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A Report of Biological Investigations at the Los Medaños Waste Isolation Pilot Plant (WIPP) Area of New Mexico During FY1978

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A REPORT OF BIOLOGICAL INVESTIGATIONS AT THE LOS MEDAÑOS WASTE ISOLATION PILOT PLANT (WIPP) AREA OF NEW MEXICO DURING FY1978

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Prepared for Sandia Laboratories by

Eastern New Mexico University
University of New Mexico
New Mexico State University
Texas Tech University

Troy L. Best and Sieglinde Neuhauser
Editors

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A REPORT OF BIOLOGICAL INVESTIGATIONS AT THE LOS MEDAÑOS WASTE ISOLATION PILOT PLANT (WIPP) AREA OF NEW MEXICO DURING FY1978

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CHAPTER 1

INTRODUCTION*

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Location and General Features of the Study Area

The U.S. Department of Energy is considering the construction of a Waste Isolation Pilot Plant (WIPP) on Sections 20, 21, 28, and 29, T22S, R31E, in Eddy County, NM. This location is approximately 40 km east of Carlsbad, NM. Biological studies during FY78 were concentrated within a 5-mi radius of drill hole ERDA 9 (encircled in Figure 1.1). Additional study areas have been established at other sites in the vicinity, e.g., the Gnome site (Sec 34, T23S, R30E), the salt lakes (14.5 km southwest of ERDA 9), and several stations along the Pecos River southward from Carlsbad, NM, to the dam at Red Bluff Reservoir in Texas. The precise locations of all study areas are presented in the chapters that follow.

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*The data presented in this document is a condensed version of the Annual Report of Biological Investigations at the Los Medaños Waste Isolation Pilot Plant (WIPP) Area of New Mexico for FY1978, T. L. Best and D. W. Jackson (eds), submitted to Sandia Laboratories, Albuquerque, New Mexico, under Sandia Contract Nos. 05-7862, 07-1489, 07-8239, 07-9252, and 13-0806. The annual report contains extensive listings of raw data, voucher specimens, detailed materials, and methods, etc. Although unpublished, the annual report is available at the Sandia Laboratories WIPP Archives, P. O. Box 5800, Albuquerque, NM 87185 1500+ pages.

The WIPP study area consists of six biologically distinct regions:

Area	Location	Description	Illustration
Creosotebush	West & southwest	Shallow calcareous soils Chihuahuan Desert vegetation	Figs 1.2 and 1.3
Mesa	Extreme northeast corner	Shallow calcareous soils Low-grazing mesquite and burrograss	Figs. 1.4 and 1.5
Dune	4 to 5 km from James Ranch Hq.	Wind-blown sand	Fig. 1.6
Hummock-mesquite	Northeast of James Ranch Hq.	Mesquite-anchored hummocks separated by bare sand	Fig. 1.7
Oak-mesquite	Between first four areas	Deep sandy soil Large expanses of sage, shinnery oak, and mesquite	Figs. 1.8 and 1.9
Aquatic		Stock tanks	Figs. 1.10 and 1.11
		Salt lakes	Figs. 1.12 -1.14
		Pecos River	Figs. 1.15 -1.17

These biological regions are discussed in more detail in the chapters that follow.

Climate and Topography of the Study Area

The Duval Potash Mine, the nearest weather station[1] to ERDA 9, is located at an elevation of 3,520 ft (1073 m), and is approximately 21 km northwest of ERDA 9. Table 1.1 is a listing of temperature and precipitation data at the mine. Sandia Laboratories has maintained a weather station at the site since 1976. The early data are now being compiled. The following discussion is based primarily on the Duval Mine data.

Rainfall during the early months of 1978 was considerably less than the previous 2 yrs (Table 1.1). However, in September there were heavy rains throughout the area. Annual precipitation is usually near 14 in., with most occurring in late summer, in early fall, and in late spring. There are often periods of drought interspersed with heavy downpours from localized thunderstorms. Precipitation patterns tend to be scattered. Certain sections of the study area may receive significant rainfall and other sections none. Runoff, even during heavy downpours in the oak-mesquite and dune areas, is rarely significant; but in the more impervious soils of the mesa and creosotebush areas, which include Livingston Ridge (Fig. 1.2), there is considerable runoff and often severe soil erosion.

The Los Medaños area is characterized by wide temperature extremes (both daily and seasonally) with typically hot summers and cool winters (Table 1.1). Summer temperatures may reach 100°F (38°C) or more in the afternoon with soil surface temperatures peaking to 155°F (68°C).[2] Winter temperatures are frequently below freezing and snowfall usually melts the following day.

Elevation varies from about 3,800 ft (1158 m) on the mesa in the northeast to about 3,400 ft (1036 m) across the oak-mesquite area that comprises most of the central and northern sections, then drops to about 3,000 ft (914 m) in the creosotebush area west of Livingston Ridge (Fig. 1.1). The general appearance of the oak-mesquite area is that of undulating, stabilized dunes.

History and Objectives of the WIPP Biological Program

Biological studies have been conducted as part of the WIPP program since August 1975.[3-5] The biological program was expanded and reoriented in late 1977 and early 1978. The data presented herein represent the first year of field studies of the expanded program.

The major objectives of the biological studies in FY78 were as follows:

- To provide on-site data for environmental assessment reports
- To provide baseline data to be used in studies of flow rates and concentration factors of radionuclides in the ecosystem
- To elucidate on the relationships between humans and species that are either potential food sources for man or that come in close contact with man
- To establish a long-term monitoring system for use in evaluating changes caused by activity at the WIPP site.

The first objective will be met with the publication of a final Environmental Impact Statement, scheduled for release in FY80. The last three objectives were to provide source material for mathemstical models. The kinds and amounts of data collected in the WIPP Biology Program were determined with future mathematical modeling in mind.

Field data collected at the WIPP site evidenced extreme annual and/or seasonal variation in many of the ecological parameters measured. Any attempt at full-scale modeling was clearly premature with data in-hand. Our ultimate goal remains the development of a meaningful ecosystem monitoring program that will permit changes to be identified and associated with a cause or causes.

Recognition of this variability, which dramatically increases the difficulty of generating a useful model, prompted a program review in late May 1979 under the auspices of the American Institute of Biological Sciences. The AIBS WIPP Biology Program Advisory Panel made a number of recommendations that modified the program objectives in the following manner:

- Obtain base-line data that will permit development of a monitoring program as defined above. The data should include
  - documentation of the range of annual and seasonal variation in ecosystem components over as many years as possible

- identification of "key" ecosystem components that are highly sensitive to the causes of variation (e.g. rainfall, grazing pressure)

- documentation of the effects of natural variation on (1) "key" components and on (2) "visible" components, espcially those used directly by man (e.g. game birds).

- Do an intensive study of the plant community immediately surrounding ERDA 9.

- Continuously identify threatened or endangered species.

- Conduct a radiological survey to establish a radioecological baseline.

The field data discussed in this report contain numerous examples of wide variation in study population on an annual or seasonal basis. It was this documentation, more than any other factor, that resulted in the review and modification of the program objectives as outlined above. These changes will result in future years of data that are immediately applicable to the development of a monitoring program at the WIPP site.

Although full-scale modeling is no longer planned or considered necessary, the chapter on ecosystem modeling (Chapter 2) has been retained, in part because it provides a useful, organized outline of the ecosystem, and in part because certain specific processes, such as salt dispersion, lend themselves to modeling; these phenomena, at least, are likely to be modelled in the future.

It should be noted, finally, that the WIPP site is by no means an undisturbed ecosystem. The region was severely overgrazed in the late 1800's; it is grazed today under a number of Bureau of Land Management (BLM) permits. Like all arid-land ecosystems, it is easily damaged and slow to recover. The impact of decades of human use are reflected in current vegetation patterns which do not resemble those recorded prior to 1870. Other man-made disturbances, such as existing and proposed roads, railroads, buildings, salt piles, etc must be considered in the development of a monitoring program (see Chapter 6 for more details).

Acknowledgments

The authors extend their appreciation to the principal investigators, numerous consultants, and students from New Mexico and Texas universities who worked together as the "WIPP Biology Team." Special thanks go to Ms. Diane Holdridge of Sandia Laboratories who provided several of the computer graphics and analyses for this report, and to Mr. Douglas W. Jackson of Southwest Research Institute who took the general goals and objectives of the WIPP biological program and converted them into a detailed program plan and flow chart of activities. The most significant individual contributor to the WIPP biological program is Dr. J. P. Brannen of Sandia Laboratories who exhibited a great awareness of the significance of a comprehensive biological program at the WIPP site.

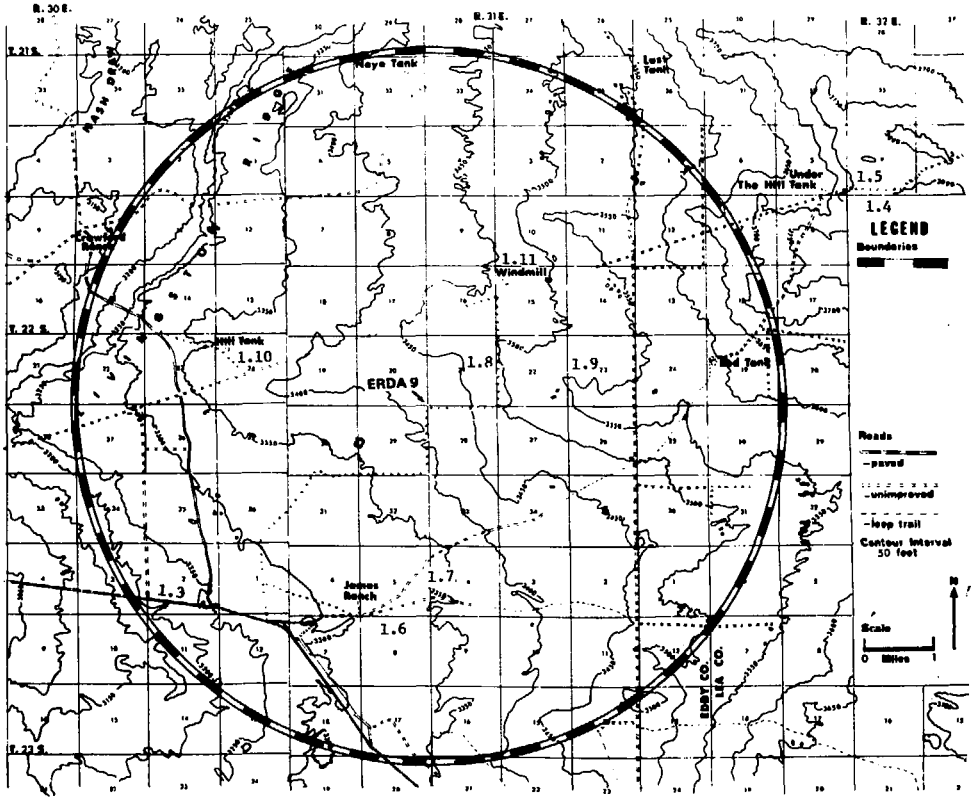

Figure 1.1. The Los Medaños WIPP Study Area 40 km East of Carlsbad, Eddy Co., New Mexico. The larger numbers on the map refer to the localities where photos for Figs. 1.3–1.11 were taken.

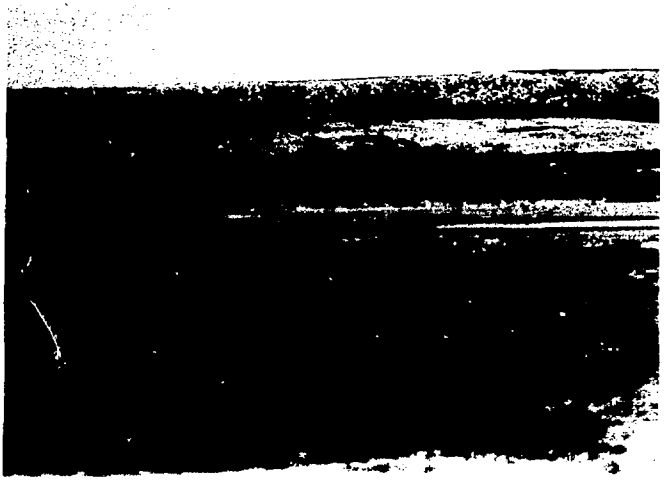

Figure 1.2. The "creosotebush area" is closely associated with Livingston Ridge in the northwestern region of the WIPP site. Dominant plants are creosotebush, mesquite, broomweed, and burrograss. 4 December 1978.

Figure 1.3. Bird, plant, and soil study plots are located in this portion of the creosotebush area on Section 2 T22S R30E. The large mound in the foreground was constructed by a banner-tail kangaroo rat, a common mammal in this area. 4 December 1978.

Figure 1.4. The "mesa area" on Section 9 T22S R32E. Dominant plants here are mesquite, burrograss, and broomweed. Torrey's yucca, prickly pear cacti, and banner-tail kangaroo rat mounds are scattered over the area. Bird, plant, and insect study grids are located here. 5 December 1978.

Figure 1.5. The mesa area slopes rather abruptly down to the sandy oak-mesquite habitat. The slopes are covered with creosotebush and is one of the few areas on the WIPP site with rocky outcrops. Golden eagles are frequently observed here in the fall and winter. 5 December 1978.

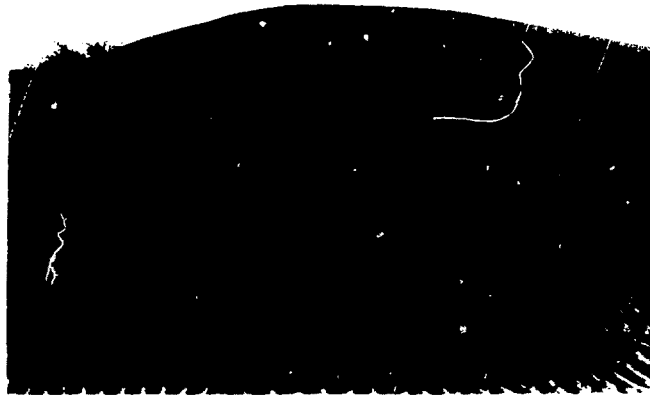

Figure 1.6. The "dune area" just east of the James Ranch Hq. (Sec 8 T23S R31E). These active dunes have scattered mesquite, sage, and sandburs as dominant plants, and are surrounded by the oak-mesquite area. 4 December 1978.

Figure 1.7. The "hummock-mesquite area" is characterized by large sand filled mesquites separated by relatively bare ground (Sec 4 T23S R31E). Sage, threeawn, and broomweed are the dominant plants between the mesquites. 4 December 1978.

Figure 1.8. The "oak-mesquite area" on Section 21 T22S R31E. This is the proposed construction site for the Los Medaños WIPP. The dominant plants here are sage, mesquite, burrograss, dropseed, yucca, and threeawn. 5 December 1978.

Figure 1.9. The "oak-mesquite area" on Section 23 T22S R31E. The 7.56 ha mammal grid is located on the NW 1/4 of this section. Dominant plants are shinnery oak, threeawn, mesquite, and sage. Mule deer tracks are frequently observed here. 5 December 1978.

Figure 1.10. Hill Tank is the major stock watering place northwest of ERDA 9 (Sec 24 T22S R30E). The earthen structure contains water most of the year. The surrounding area is dominated by mesquite, threeawn, and shinnery oak. 5 December 1978.

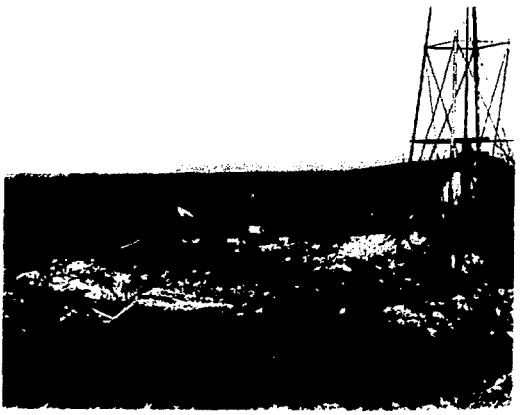

Figure 1.11. Windmill Tank (Sec 15 T22S R31E) is one of the few permanent sources of fresh water on the WIPP site (also the Crawford and James Ranch Hq.). The area immediately around the windmill has large mesquites, with shinnery oak, threeawn, broomweed, and scattered yucca. 5 December 1978.

Figure 1.12. Laguna Grande de la Sal is the largest of the salt lakes in the area (T23S R29E). The ripple is a large subsurface spring that flows into the lake. "Pupfish Spring" flows into the lake here also. 4 December 1978.

Figure 1.13. "Pupfish Spring" is located near the northern end of Laguna Grande de la Sal (Sec 4 T23S R29E). Its less saline water supports a small population of pupfish. The spring is less than 1.5 m deep with most areas less than 10 cm. The vegetation here is very salt tolerant. 4 December 1978.

Figure 1.14. Several other salt lakes are located between Laguna Grande de la Sal and the WIPP study area around ERDA 9. These have a great deal of partially submerged vegetation (mostly salt cedar) as well as partially inundated fences, livestock and corrals, and at least one windmill. 4 December 1978.

Figure 1.15. Harroun Crossing is located on the Pecos River northeast of Malaga (SW 1/4 Sec 1 T24S R28E). This view is a few hundred meters upstream from the crossing where the Black River (center) flows into the Pecos River (foreground). Thick salt cedars line the shore of both rivers. Cotton and alfalfa are grown near here. 5 December 1978.

Figure 1.16. "Malaga Bend" is located on Sections 16 and 17 T24S R29E. This area receives surface and subsurface runoff from Nash Draw, the main drainage of the WIPP site. The constant subsurface flow of salt water into the Pecos River here causes a significant change in salinity, flora, and fauna from here southward. 5 December 1978.

Figure 1.17. "Pipeline Crossing" is located at the juncture of Sections 5 and 8 T26S R29E. Salt cedar persists as the dominant shoreline plant. Creosotebush and catclaw are plentiful in this area. The water here is very saline and there is relatively little diversity in the fish fauna. 5 December 1978.

Table 1.1. Climatological Data for Duval Potash Mine, Eddy Co., New Mexico, August 1975 - September 1978*

Month/Year	Temperature (°F) Mean	Maximum	Minimum	Total Precipitation (in.)
August 1975	78.4	98	62	1.78
September 1975	68.8	93	43	1.45
October 1975	63.6	91	36	0.15
November 1975	52.3	83	21	0.00
December 1975	44.1	76	13	0.39
January 1976	41.5	71	17	0.01
February 1976	52.6	80	25	0.33
March 1976	54.5	83	31	0.15
April 1976	63.3	89	36	3.27
May 1976	66.3	94	42	2.36
June 1976	78.3	103	56	0.10
July 1976	76.8	97	60	1.82
August 1976	78.6	100	56	0.71
September 1976	70.4	92	45	3.97
October 1976	56.1	84	32	2.82
November 1976	43.9	75	5	1.15
December 1976	41.4	68	14	0.00
January 1977	37.3	65	9	0.12
February 1977	47.7	81	19	0.17
March 1977	51.2	79	17	1.08
April 1977	62.1	89	32	1.32
May 1977	72.5	100	51	1.40
June 1977	80.8	106	61	2.25
July 1977	82.2	101	62	0.55
August 1977	83.5	104	67	0.26
September 1977	78.8	100	59	0.17
October 1977	64.4	98	42	1.60
November 1977	53.4	81	29	0.11
December 1977	48.0	81	19	0.00
January 1978	38.4	71	10	0.14
February 1978	41.8	72	18	0.52
March 1978	54.0	88	23	0.23
April 1978	67.0	93	36	0.24
May 1978	71.6	99	38	0.96
June 1978	80.5	107	55	2.20
July 1978	83.3	106	51	0.43
August 1978	79.7	103	59	1.29
September 1978	70.2	96	49	6.50

*Data taken from NOAA, Climatological Data for New Mexico (1975-1978)

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2. Steve Waldschmidt, University of Wisconsin, Dept of Zoology, Madison, Wisconsin, personal communication.

3. H. G. Wolfe et al (eds.), An Environmental Baseline Study of the Los Medaños Waste Isolation Pilot Plant (WIPP) Project Area of New Mexico: A Progress Report, SAND77-7017 (Albuquerque: Sandia Laboratories, 1977), 114 pp.

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5. New Mexico Environmental Institute, An Environmental Baseline Study of Los Medaños Waste Isolation Pilot Plant (WIPP) Project Area of New Mexico: A Progress Report, NMEI Project No. 3110-308, 1978, 68 pp. Appendix: 117 pp.

CHAPTER 2

MATHEMATICAL MODELING OF ECOSYSTEMS AND THE WIPP STUDY: A REVIEW OF RELEVANT LITERATURE

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Introduction

This chapter is a review of the literature concerning mathematical modeling of ecosystems which is particularly relevant to the WIPP biological studies. Two bodies of literature were reviewed: (1) modeling of radionuclide transfer in ecosystems, and (2) modeling in the IBP Desert and Grassland Biome Programs. The first of these types of models is used to predict the transfer of radionuclides in an otherwise steady state ecosystem (Wiegert 1975), while the IBP programs have attempted to discover and model the mechanisms of ecosystem responses to perturbations (Reichle 1975). Since the introduction of radionuclides to an ecosystem may perturb the system, which would in turn alter the transfer of radionuclides, both approaches are pertinent to the WIPP study.

This report will acquaint the reader with the major literature of both modeling approaches and will summarize the strengths and limitations of the techniques described. Frederick M. Fisher reviewed the modeling of radionuclide transfer and Herbert D. Grover reviewed the models developed for the IBP Grassland and Desert Biome Programs.

Prediction and Modeling of Radionuclide Transfer in Ecosystems
(Frederick M. Fisher)

This section is a review of the major methods of modeling and predicting radionuclide transfer in ecosystems. Fifty-nine radionuclides have been identified as possibly worthy of study in the WIPP biological program (D. W. Jackson, pers. comm.). It should not be necessary to model the behavior of all of these radionuclides, using the most complex model available, since many of the radionuclides will be present in extremely small amounts.

Raines et al (1969) discuss the use of a hierarchy of models, ranging from simple models containing conservative assumptions (giving highest dose to man) to complex models with more realistic assumptions. This hierarchical approach was used to assess the radionuclide dose to man resulting from the use of nuclear explosives for the excavation of a sea-level, trans-isthmian canal. Dosages were first predicted using the simplest, most conservative models, and these predictions were compared with criteria for safe levels of exposure. In this fashion, 287 radionuclides were eliminated from further consideration because predicted exposure was insignificant. Transfer of the remainder was evaluated using more complex models. It seems possible that the WIPP study could present similar problems; therefore, an attempt has been made here to present a similar hierarchy of modeling techniques. The major attributes and limitations of the techniques are discussed, as well as the possible application of the techniques to the WIPP study.

Prediction of Steady State Distribution of Radionuclides

The following techniques can be used to assess the distribution of radionuclides assuming that the rate of release is constant and that the ecosystem is in steady state.

Specific Activity -- Specific activity is defined as the ratio of radioactive atoms to total atoms of the same element. If the concentration of the stable element is known for the various ecosystem components,

and if the point of entry of the radionuclide to the food chain is given for a specific activity, the steady state distribution of the radionuclides can be predicted. The basic assumptions of the technique are that the radioactive and stable forms of the element are mixed completely and that there is no biological discrimination between the forms. In the simplest application of this principle, physical decay and excretion factors--which will reduce the concentration of radionuclides in the food chain--are ignored so that the predicted specific activity could be equal in all steps of the food chain (Kaye and Nelson 1968, Reichle et al 1970). Kaye and Nelson (1968) discuss some studies in which the specific activity technique has been applied.

Bioconcentration Factors -- A large amount of data has been collected concerning the concentration of elements (mostly radioactive forms) in organisms compared to the concentration in the food base. These data are generally expressed in the form of a ratio called the bioconcentration factor (BCF). If BCFs for each step of a food web are known, and if a concentration of radionuclide at the point of entry to the food chain is given, the steady state distribution of the radionuclide can be predicted. It is assumed that physical decay is negligible (Reichle et al 1970, Kitchings et al 1976). Bioconcentration factors are highly variable between different organisms, ecosystems, and elements. Some generalizations can be made based on the literature but the data are too variable to be useful for accurate prediction of radionuclide fate in an ecosystem for which no previous data are available. For example, Kitchings et al (1976) cite data in which the cesium BCF for bobcats preying on cotton rats varied from 6.9 to 18.7 depending upon soil type, and concentration factors of strontium for mammalian herbivores eating grass varied from 0.19 to 8.4. Bioconcentration factors have normally been determined following a release of some radionuclide to the environment but can also be determined from the stable element distribution.

Other Elements as Chemical Analogues -- Radioisotopes of strontium and cesium are two of the most studied radionuclides because of their importance in radioactive fallout (Russell 1967). Although the behavior of strontium in food chains is usually similar to calcium, and that of

cesium usually similar to potassium, the relationships are only qualitative, and sometimes break down. Reichle and Crossley (1969) found in lab experiments that the cricket (Acheta domesticus) demonstrated a 25% discrimination against cesium-137 in the presence of potassium-42. Using the ratio of 0.75 Cs/K they were able to predict radionuclide distribution in a cryptozoan food chain. However, Reichle et al (1970) cite data in which calcium and potassium in fish varied independently of levels in the water but strontium was directly proportional to levels in the water, illustrating that the use of other elements as chemical analogues for radionuclides is not always justified.

Summary -- Specific activities can be used to predict the steady state distribution of long-lived radionuclides, assuming complete mixing and no biological discrimination between radioactive and stable forms. Calcium and potassium have been used as analogues for strontium and cesium, respectively; but there seems to be enough evidence of biological discrimination to discourage this practice. Bioconcentration factors are at best a descriptive parameter, showing great variability depending upon the ecosystem, season, etc.

Uptake-Retention Models

The basis for modeling the time-dependent behavior of radionuclides in food chains is the uptake-retention model. These models are based on first-order linear differential equations and thus can be solved analytically. The models can be applied to individual organisms or to populations of organisms. Because the majority of modeling of radionuclide transfers is of this type, and because these models form the basis of the more complex ecosystem models, uptake-retention models will be treated in some detail.

Robinson (1967) described the loss of organochlorine insecticides from tissues as decreasing at a rate proportional to the concentrations in the tissues at that time. This can be expressed mathematically as:

$$\frac{dY}{dt} = -k_b Y \qquad (1)$$

where t is time, Y is the concentration (or total content) in the tissues, and k_b is the fraction of Y lost per unit time. This differential equation may be solved for Y analytically:

$$Y = Y_o e^{-k_b t} \qquad (2)$$

where Y_o is the initial concentration of radionuclide. This equation allows prediction of the radionuclide content at any time following a pulse input and can be used to approximate the losses from whole organisms or from populations. The coefficient k_b can be determined experimentally by introducing a dose of radionuclide to the organism and measuring the decrease in radioactivity present in the organism. The k_b value can then be derived from the loss half time $T_{1/2b}$ (Reichle et al 1970, O'Neill 1971) or from the slope of the natural log of body burden Y plotted against time (O'Neill 1971). The former relationship is described by the equation

$$k_b = \frac{\ln 2}{T_{1/2b}}, \qquad (3)$$

and the latter by

$$\ln Y = \ln Y_o - k_b t \quad . \qquad (4)$$

If physical decay is significant, it is easily accounted for since it is described by an exponentially decreasing function. The two coefficients, k_b for biological loss and k_r for radioactive decay, are additive with the

sum referred to as the effective loss coefficient k. Reichle et al (1970) described a method for using the biological and physical half lines to calculate k.

The approach above assumes that the entire organism acts as a single tissue with respect to radionuclide retention; but because organisms are collections of tissues, the goodness of fit can often be improved by developing models with more than one exponentially decaying component. Two component retention curves of the following general form have been used most frequently:

$$Y = Y_o\left(p_1 e^{-k_1 t} + p_2 e^{-k_2 t}\right) , \qquad (5)$$

where k_1 and k_2 are the fractional-loss constants for two pools within the organism, which initially contributed proportions p_1 and p_2 ($p_1 = 1 - p_2$) to the total body burden of the organism (Reichle and Crossley 1965, Eberhardt 1969, Schreckhise and Whicker 1976). O'Neill (1971) described a method to calculate the k values for two-component retention models.

Schreckhise and Whicker (1976) suggested that retention of Sr by mule deer can be approximated by a two-component curve because the fast component represents the loss of unassimilated strontium while the slow component represents turnover of Sr which was assimilated into the bone. They found that a three-component model gave no better fit than the two-component model and that a power-law model gave poorer fit than did the exponential models.

Once the coefficients have been determined, the retention curve can be used to determine intake of radionuclide. For constant intake, accumulation and retention of a radionuclide in an organism can be described by the equation

$$\frac{dY}{dt} = I - kY \quad . \qquad (6)$$

This differential equation can be analytically solved to yield

$$Y = \frac{I}{k}\left(1 - e^{-kt}\right) + Y_o e^{-kt} \tag{7}$$

(Eberhardt et al 1976). The general equation for the ith-component accumulation-retention equation (where Y_o equals 0) is

$$Y = \sum_{i=1}^{n}\left(Ip_i/k_i\right)\left(1 - e^{-k_i t}\right). \tag{8}$$

Equation (7) can be rearranged:

$$I = k(Y - Y_o e^{-kt})/(1 - e^{-kt}) \quad . \tag{9}$$

If k is known, I can be calculated from a series of body burden (Y) measurements by assuming constant intake I for a time interval t, where Y_o is the initial body burden and Y the final body burden. If the concentration C of radionuclide in the food is known, then the weight intake R of food can be easily calculated since:

$$R = I/C \tag{10}$$

Cadwell and Schreckhise (1976) demonstrated the application of these relationships to grass consumption by grasshoppers.

Intake may be specified by any appropriate mathematical function. Crossley and Reichle (1969) found that the cesium content of leaf litter in a labeled Liriodendron forest decreased exponentially after leaf fall, and Turner (1963) found that radioiodine content of vegetation decreased exponentially following pulse inputs from weapons testing. An uptake-retention equation for consumers feeding on these food sources can be developed by substituting

$$RC_o e^{-k_f t}$$

for I where C_o equals the initial concentration of radionuclide in the food and k_f is the loss coefficient of the radionuclide from the food (not necessarily equal to k_r):

$$\frac{dY}{dt} = RC_o e^{-k_f t} - kY \quad . \tag{11}$$

Solving for Y:

$$Y = \frac{RC_o}{(k_e - k_f)} \left[e^{-k_f t} - e^{-kt} \right] + Y_o e^{-kt} \quad . \tag{12}$$

The biological loss coefficient k_b can vary with the sex, stage of the life cycle, size of the individual, temperature, and chemical form of the radionuclide. Whether these differences are important depends on the degree of resolution needed to achieve the modeling goals. Schreckhise and Whicker (1976) demonstrated a method of accounting for changes in excretion rate k_b during the life cycle of mule deer. Bucks of different ages and in different stages of the antler growth cycle were found to have varying k_b coefficients which could be predicted by a seasonally oscillating sine wave superimposed on a line with a slope related to the age of the buck.

Although k_b values are normally estimated from laboratory or field experiments, there is some evidence to suggest the existence of systematic relationships between the biological half life ($T_{1/2b} = \ln 2/k_b$) of the more important long component of the retention curve and body size which

might reduce the need for experiments of this type (Eberhardt 1969, Reichle et al 1970, Kitchings et al 1976). Although there seems to be general agreement that the relationship takes the form of the power function

$$T_{1/2b} = mw^n \tag{13}$$

(where w is the weight of the organism, and m and n are constants), few data are available to identify the exact nature of the relationship. Reichle et al (1970) presented two relationships for cesium turnover, one for arthropods with calcified skeletons and cold-blooded vertebrates, and one for insects and warm-blooded vertebrates. One controversy has concerned the fact that the power coefficient n has often been found to be much lower in studies of radionuclide turnover than the value of 0.75 found in studies of metabolic rate. Kitchings et al (1976) suggested that this resulted because the short component of the excretion curve was being ignored, while Eberhardt (1969) suggested that the value of n within species of homeotherms was 0.75 while differences between species were accounted for by the coefficient m.

All models discussed up to this point have been based on continuous functions which assume that the animal eats at a constant rate for 24 hours a day. A single component exponential loss curve can be revised to a discrete form (Eberhardt et al 1976):

$$Y = Y_1e^{-kt_1} + Y_2e^{-kt_2} + \ldots + Y_ie^{-kt_i} \tag{14}$$

where Y_i represents the quantity of contaminant in a meal ingested at time t_i (t_i represents the time interval between the present and the time of the ith most recent meal). This model represents meals as being consumed at intervals of time. When the time interval is reduced to 0, then the model is reduced to the continuous form. Turner (1963) developed a form of this which included an exponentially decreasing input of radioiodine. When solved, this model predicted body burdens 8% lower than the

continuous version. This type of model also has been used with stochastic simulations, where the quantity of containment was randomized to reflect the distribution found in the field (Turner and Jennrich 1967).

Summary -- The basic uptake-retention model is given by the differential equation:

$$\frac{dY}{dt} = I - kY \quad . \tag{6}$$

Solving for Y:

$$Y = \frac{I}{k}(1 - e^{-kt}) + Y_o e^{-kt} \quad . \tag{7}$$

This model, or more elaborate models based on it, have been used to describe and analyze radionuclide turnover in food chains in a number of studies. The application of these techniques is illustrated in the studies which are summarized in Table 2.1.

Multiple Compartment Models for Prediction of Radionuclide Transfer

Linear Differential Equation Models -- The use of systems of linear differential equations to predict the time-dependent transfer of radionuclides in ecosystems is a direct extension of the uptake-retention models and, in fact, the retention function is often used directly in these models. The rates of all transfers between compartments are usually assumed to be directly proportional to the content of the donor compartment so that all equations assume general form (adapted from O'Neill 1971, Vanderploeg et al 1975, 1976, and Eberhardt et al 1976):

$$\frac{dY_j}{dt} = \sum_{i+j}^{n} a_{ij}Y_i - \left(k_b + k_r + \sum_{k=1}^{m} a_{jk}\right) Y_j + F_n \tag{15}$$

where Y_j is the content of the compartment of interest, Y_i is the content of one of n donor compartments, a_{ij} is the fractional transfer coefficient from the donor compartment to the compartment of interest, and a_{jk} is one of the transfer coefficients from the compartment of interest to m recipient compartments. F_j represents the rate at which radionuclides enter compartment j from the surroundings, and is termed the forcing function. Other parameters are as previously described.

A number of methods for determining values for transfer coefficients are illustrated in the various models surveyed for this paper. The optimum method is to measure the transfers directly; then the coefficient is simply the proportion of the total content of the donor compartment transferred per unit time.

The use of systems of linear differential equations is mathematically advantageous, since they may be solved using analytical methods including matrix algebra which is readily adaptable to a digital computer (Wiegert 1975, Eberhardt et al 1976). Many systems analysis techniques are available to analyze the mathematical behavior of these systems (Wiegert 1975).

Systems of linear differential equations are often criticized for representing unrealistically a number of ecological interactions. However, the method is applicable to prediction of many of the transfers of radionuclides in an otherwise steady state ecosystem (Wiegert 1975) because the amount of radionuclide transferred in a consumption process must be directly proportional to the concentration in the food. Given a known transfer of biomass, the transfer of radionuclides is a linear function of the donor compartment, so that in this case this modeling technique can be considered to be mechanistic. It is difficult to evaluate the use of linear differential equations for transfers other than consumption processes because of lack of documentation. Linear modeling has been used frequently to describe rates of breakdown of decomposing organic matter (Olson 1963, Gosz et al 1973, Hunt 1977).

Most models of radionuclide transfer have made use of constant transfer coefficients. This implicitly assumes that there is no change in the

transfer of biomass during the period of interest. This assumption can be justified in some cases, such as in ecosystems with little seasonal fluctuation (tropical ecosystems), short-term laboratory studies, and pulse inputs of short-lived radionuclides (iodine-131).

In seasonally fluctuating environments, variable coefficients are necessary to provide adequate fit to the data (Eberhardt et al 1976). Seasonal fluctuations of physical parameters will result in regular changes in biomass transfer, which in turn will cause changes in the transfer of radionuclides. These changes can be accounted for empirically by making coefficients a function of time (Eberhardt and Hanson 1969, Gist et al 1973, Eberhardt et al 1976), or somewhat more mechanistically by making the coefficients a function of physical parameters such as temperature and moisture (O'Neill 1971).

Biomass-Based Models -- Radionuclide-based models of food webs consisting of linear donor-controlled differential equations can be considered to be mechanistic because the transfer of radionuclides is directly proportional to the transfer of biomass. It is generally agreed, however, that the control of the transfer of biomass (energy) cannot be realistically modeled using only equations of this type. Nonlinear differential equations are required to model ecological relationships, such as predator-prey or consumer-producer interactions, because the transfer of biomass is dependent upon both the donor (prey, producer) and the recipient (predator, consumer) compartments (O'Neill 1971, Wiegart 1975). Biomass-based models consisting of donor-controlled differential equations can accurately reproduce the system behavior near equilibrium but cannot predict behavior resulting from perturbations because linear functions have been used to approximate nonlinear relationships.

Two specific goals can be established for development of a biomass-based model of radionuclide transfer: (1) prediction of changes in radionuclide transfer that would result from changes in biomass transfer such as a reduction in grazing pressure or long-term changes in weather; and (2) prediction of changes in biomass transfer resulting from increased

radioactivity and the resultant changes in radionuclide transfer. I know of no extant models which have the capability to achieve these goals.

To predict changes in radionuclide transfer resulting from changes in biomass transfer (goal), a biomass-based model, or models, capable of responding to the appropriate perturbations must be determined as a function of biomass and other factors. Because concentration of some elements in some organisms is biologically indeterminant, depending instead on the concentration in the environment or the food, simple measurements of element content of the ecosystem components will probably be insufficient to achieve this goal.

Predicting the changes in biomass transfer resulting from increased radioactivity will present additional difficulties. It may be impossible to run field experiments involving introduction of radionuclides or irradiation from a point source. Several field studies have been undertaken to assess the effect of radiation on organisms and ecosystems (Woodwell and Marples 1968, Odum et al 1970, French et al 1974). The most applicable study appears to be the one carried out at the Nevada Test Site, some aspects of which are discussed by French et al (1974). O'Farrell and Emery (1976) have published a comprehensive annotated bibliography (333 references) of the ecological studies of this area. Since all of these studies were carried out using a single point source of radiation, a major modeling task will consist of developing realiatic functions to describe the effects of different levels of radiation emitted from radionuclides cycling within the ecosystem.

Stochastic Modeling -- Models in which all input parameters and coefficients consist of means are termed deterministic. Randomness is a common phenomenon in nature (O'Neill 1971), and arid environments are especially subject to fluctuations, particularly rainfall. This argues for the incorporation of probabilistic, or stochastic, elements into models. O'Neill (1971) represented temperature as a normal distribution around a sine wave function; a similar method could be used to describe the yearly distribution of rainfall. Another reason for using stochastic

models is that with respect to health safety, the high extremes of radionuclide concentration are sometimes of more concern than the mean (Turner 1963).

Stochastic simulation techniques can also be used to analyze sources of error in models. Intuitively, a model of greater complexity would be expected to reproduce system behavior more accurately. However, there are numerous measurement problems associated with the field and laboratory experiments necessary to determine parameters. Increasing model complexity results in reduced systematic bias, but it also increases uncertainty due to measurement error (O'Neill 1973). O'Neill (1973) hypothesized that measurement error could be compounded in very complex models so that their predictions would actually be less accurate than models of moderate complexity. To test this hypothesis, an artifical system was developed and models of differing complexity were constructed to describe it. Stochastic simulations were performed with each coefficient taken as a normally distributed variable with a standard deviation of 10% of the mean. Error was separated into components resulting from systematic bias and measurement error. Under these conditions, O'Neill (1973) demonstrated that more complex models could have reduced predictive ability as a result of measurement error, and that in some cases linear models were more accurate than nonlinear models because the measurement error of the coefficients was not multiplied.

Modeling of Plant-Soil Relationships of Radionuclides -- The goal of many models of radionuclide transfer in ecosystem has been to study the impact of fallout on man. These modeling studies were often rather short term because they were concerned with high initial levels of radionuclides that were present soon after the fallout event. Under these conditions, uptake from the soil of three major radionuclides was negligible and the major input to food chains in all cases was from foliar interception (Garner 1972). Strontium-90 absorption from the soil seems to be proportional to the amount of calcium in the soil, and due to the large amount of the latter, total uptake of the radionuclide is small. The rapid physical decay of the short-lived radionuclide, Iodine-131, makes it of little concern in the soil. Cesium in many temperate soils becomes firmly

bound to clay and has only limited availability to plants (Garner 1972), in contrast to the relatively mobile potassium ion. However, cesium uptake was significant in lateritic and organic soils (Garner 1972).

Garner (1972) describes a model for cesium transfer from fallout to milk which ignores the soil contribution and which has been applied at ten sites in the U.S. In two sites, Tampa, Florida (lateritic soil), and Seattle, Washington (organic soil), the model was not applicable apparently because uptake from the soil was significant. Even in the other eight sites there was a tendency, following the first several years, for the model to underestimate concentrations in milk suggesting that cesium in the soil was slowly being made available for plant uptake. This source of cesium is included as a linear transfer in some more recent models such as the terrestrial transport model described by Booth et al (1973) and Parzyck et al (1976). Sasscer et al (1973) and Jordan et al (1974) presented a sophisticated model of tritiated water dynamics where the soil is treated as 40 to 50 compartments, each 1 cm deep. A model of radiostrontium migration in soils has been published by Anochin et al (1967). Several reviews have been published concerning the behavior of radionuclides in soils and plants, e.g., Menzel (1965), Schulz (1965), Russell (1967), and Garner (1972).

A related subject is the modeling of sediment-water interactions in aquatic ecosystems. Both Adams et al (1976), and Vanderploeg et al (1975, 1976), include the sediments in their models but the equilibriums are described only with linear constant coefficient transfers. This may be a valid approach but there is insufficient documentation at present to allow judgment. The lake model of Vanderploeg et al (1975, 1976) appears to have no provisions for stratification and seasonal turnover, a physical factor with important effects on sediment-water interactions.

Evaluation of Models -- All models of radionuclide transfers to date have made use of linear coefficient differential equations. These models are unable to predict transfers if the ecosystem control mechanism is perturbed; but since radionuclide transfer is a linear function of biomass transfer, the models should be able to predict radionuclide transfer in

food webs under steady state or seasonally oscillating conditions. Biomass-based models will be necessary to predict the effects of other ecosystem changes on radionuclide transfer, and to predict the effects of radioactivity on ecosystem processes. Stochastic modeling allows prediction of the high extremes (important for health safety) and can account for the randomness present in arid environments. Stochastic simulations have also been used to determine sources of error in models. There has been less modeling of radionuclide transfers from soils to plants than for food chains, and it is difficult to evaluate the models with so little documentation. The application of multiple compartment models to the problem of radionuclide transfer is illustrated by the studies summarized in Table 2.2.

Modeling Radionuclide Transfer at the WIPP Site

The specific activity concept can be adapted for use in a compartment model (Bloom and Raines 1970; Odum et al 1970; Vanderploeg et al 1975, 1976). This approach seems well suited to the WIPP project. The model can be constructed based on the compartmental content and the transfer of the stable forms of the elements. Impact assessment can be easily carried out by applying the specific activity concept. Some assumptions of the approach are that the radioactive and stable forms of the element are completely mixed and that there is no biological discrimination between the two (Kaye and Nelson 1968). Mixing is less complete in terrestrial ecosystems than in aquatic systems, and the erratic moisture regime at the WIPP site will intensify the problem. The functioning of the soil is complex and poorly understood; and the appearance of poor mixing could result simply because a soil process has not been adequately studied. There are a number of instances in the literature where, based on budget techniques, turnover of a material in the soil was thought to be best represented as a single compartment. Tracer experiments later showed that the turnover could be better conceived as consisting of two compartments, a small rapidly turning-over compartment and a large slowly turning-over compartment (tritiated water: Bloom and Raines 1970; cesium: Garner 1972; organic nitrogen: Clark 1977). This type of error is inherent in standard nutrient budget techniques (Bloom and Raines 1970), but the only

alternative is to experimentally introduce radionuclides to the ecosystem, a practice not likely to be approved.

It is worth reiterating that the use of other elements as analogues for radionuclides, such as calcium for strontium or potassium for cesium, appears to be inadequate as a basis for quantitative prediction of radionuclide transfer. In a lake, calcium was found to be biologically determinant while strontium was biologically indeterminant (Reichle et al 1970). Potassium and cesium behave quite differently in soils.

The biology program should undoubtedly be based on a mechanistic biomass-based model, which by definition must be fairly complex to represent the entire ecosystem. Some ideas concerning the incorporation of radionuclide transfer into such a model were presented earlier. There are several good reasons for developing simpler models, probably of the linear donor-controlled radionuclide-based type: (1) Assuming little change in ecosystem function, the simpler models can simulate the transfer of radionuclides as well as more complex models. (2) The relative simplicity of these models makes them more adaptable to impact assessment where numerous simulations will be required for all of the scenarios. (3) Linear donor-controlled radionuclide-based models would require no additional data than a complex biomass-based model and could be constructed by an individual or a few individuals. (4) The great complexity of a biomass-based model of radionuclide flow may be a liability in terms of predictive ability (O'Neill 1973). A major disadvantage concerning the application of linear radionuclide-based models to an arid ecosystem is probably the assumption that the ecosystem is in steady state or is oscillating regularly. Wiens (1977) has argued recently that avian food webs in arid environments are rarely, if ever, in equilibrium.

The arguments for including stochastic elements in models seem to be particularly applicable to the WIPP project. (1) The rainfall (and possibly other parameters) is highly erratic and can best be represented probabilistically. (2) Stochastic simulations can be adapted to determine sources of error in models (O'Neill 1973). (3) The major goal of the modeling is presumably for health-safety reasons, in which case the high

extremes in concentration of radionuclides are of primary interest rather than the expected mean (Turner 1963).

Summary

The specific activity concept can be used to predict the distribution of radionuclides in a steady state ecosystem assuming complete mixing and no biological discrimination between stable and radioactive forms of the elements. The possibility of biological discrimination can be minimized by using stable isotopes of the same element as analogues for the radionuclides.

The turnover of radionuclides in a single animal or population can be described using uptake-retention equations of the general form:

$$\frac{dY}{dt} = I - kY \qquad (6)$$

where Y is the radionuclide content of the animal or population, k is the proportion of Y lost per unit time, and I is the uptake per unit time. The equation thus describes the net change in radionuclide content dY occurring in an infinitesimal period of time dt. In most applications, the loss coefficient k consists of the sum of k_b and k_r, and the proportions of Y lost per unit time due, respectively, to biological excretion and radioactive decay.

Systems of linear differential equations have been used to predict the transfer of radionuclides through food chains and whole ecosystems. The general form of these equations is:

$$\frac{dY_j}{dt} = \sum_{i+1}^{n} a_{ij}Y_i - \left(k_b + k_r + \sum_{k=1}^{m} a_{jk}\right) Y_j + F_n \qquad (15)$$

where Y_j is the radionuclide content of the compartment of interest, Y_l is the content of one of n donor compartments, a_{ij} is the fractional transfer coefficient from the donor compartment to the compartment of interest, and a_{jk} is one of the transfer coefficients from the compartment of interest to m recipient compartments. F_j represents the rate at which radionuclides enter the compartment of interest from the environment. This type of model is applicable to food chains under equilibrium or regularly oscillating conditions. In this case, transfers of radionuclides are proportional to the concentration in the food. Due to lack of information, it is difficult to evaluate the use of equations of this type to predict other transfers such as from soil to plants. Systems of linear differential equations are inadequate to predict changes in the transfer of biomass (energy) in the ecosystem, and models employing nonlinear differential equations will be necessary to predict the effect of ecosystem perturbations on radionuclide transfer.

Stochastic simulation techniques can be used to predict the extreme high radionuclide concentrations most important for health-safety, to account for the randomness present in arid environments, and to determine sources of errors in models.

The specific activity concept can be adapted for use in both linear and nonlinear differential equation models and the approach is well suited to the WIPP project. The model is constructed based on a field study of the transfer of the stable analogues of the radionuclides. The impact of the introduction of radionuclides can then be assessed by applying the specific activity concept.

Table 2.1. Uptake-Retention Models. The radionuclide studied, the type of environment studied, and the study objective are presented for some uptake-retention models.

Reference	Radionuclide	Environment	Study Objective
Cadwell and Schreckhise 1976	^{32}P	Grassland	Estimate consumption by grasshoppers
Crossley and Reichle 1969; Reichle and Crossley 1965, 1969	^{137}Cs, ^{134}Cs, ^{42}K, ^{24}Na	^{137}Cs tagged *Liriodendron* forest	Describe radionuclide dynamics in a forest floor food web
Schreckhise and Whicker 1976	Radiostrontium	Terrestrial: Arid and semiarid	Determine seasonal change of retention coefficients
Turner 1963	^{131}I	Terrestrial: Arid and semiarid	Assess impact of Sedan nuclear weapons test. Predict ^{131}I in rabbits
Turner and Jennrich 1967	^{131}I	Terrestrial: Arid and semiarid	Assess impact of Sedan nuclear weapons test. Predict ^{131}I in rabbits using stochastic simulations

Table 2.7. Multiple Compartment Models. Pertinent information for some multiple compartment radionuclide transfer models is summarized. The models were first classified with respect to the solution technique (analytical or simulation), the method of parameter input (deterministic or stochastic), and the type of transfer coefficient employed (linear constant coefficient (LCC)) or linear variable coefficient (LVC). The model compartments were classified as abiotic or biotic usually depending upon whether the element in question was incorporated as an organic molecule. The total number of compartments of each type and the number of flows are shown for each model. Also included are the radionuclide studied, the type of environment studied, the study of objectives, additional comments.

Reference	Model Type	Compartments: Abiotic	Compartments: Biotic	Compartments: Flows	Radionuclide	Environment	Study Objectives	Comments
Adams et al 1976	Analytical Determ. LCC	2	2	8	Tritium	Lake Erie marsh	Describe tritium transfer following experimental introduction	Sediment model includes a second-order partial differential equation
Booth et al 1973 Parzyck et al 1976	Analytical Determ. LCC	5	5	14	^{137}Cs, ^{90}Sr, ^{131}I, ^{32}P, ^{185}W, ^{203}Hg, ^{204}Tl	Generalized terrestrial ecosystem	Predict impact of Oak Ridge facility and the Quad cities nuclear generating station	Predicted ^{131}I values for Oak Ridge and Quad cities are within the range of observed
Bloom and Raines 1970	Simulation Determ. LCC	5	3	14	Tritium	Tropical rain forest	Predict impact of canal excavation using nuclear explosives	Specific activity based model
Eberhardt and Hanson 1969; Eberhardt et al 1976	Simulation Determ. LVC	1	3	9	^{137}Cs	Terrestrial Arctic	Predict dose to man from fallout	
Gist et al 1973	Simulation Determ. LVC	0	3	10	^{131}I	Terrestrial Arrid and semiarid	Predict radioiodine in mule deer	Retention coefficients change seasonally
Jordan et al 1974; Sasacer et al 1973	Analytical Determ. LVC	40-50	1	200-250	Tritium	Terrestrial Old field, Illinois	Predict tritiated water movement in soil	Soil treated as 40-50 1-cm-thick layers
Kay and Hall 1969	Analytical Determ. LCC	1	4	12	Generalized	Terrestrial tropic hypothetical banana plantation	Sensitivity analysis of parameters	Discusses purpose of sensitivity analysis
Kay and Nelson 1968	Specific activity analytical	-	-	-	Generalized	Generalized	Predict radionuclide transfer	Cites previous applications of specific activity
Odum et al 1970	Simulation Determ. LCC	5	4	22	Tritium	Tropical rain forest	Predict impact of canal excavation using nuclear explosives	Specific activities based model
Olson 1965	Simulation Determ. LCC	2	5	21	^{137}Cs	^{137}Cs tagged Liriodendron forest	Simulate Cs dynamics following an experimental introduction	
O'Neill 1971	Simulation Stochastic LVC	1	15	50	^{137}Cs	^{137}Cs tagged Liriodendron forest	Simulate radionuclide dynamics in forest floor food web	
Raines et al 1969	Analytical Determ. LCC	1	1	2	53 radionuc.ides	Generalized	Predict impact of canal excavation using nuclear explosives	Hierarchy of models based on specific activity used to assess impact of 318 radionuclides
Raines et al 1969	Analytical Determ. LCC	3	5	11	31 radionuclides	Generalized	Same as above	Same as above
Vanderploeg et al 1975, 1976	Analytical Determ. LCC	4	9, 10	24, 26	Generalized	Aquatic	Experimental application of ^{137}Cs in a eutrophic and an oligotrophic lake	Specific activities based model

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A Review of the Grassland and Desert Biome Programs
(Herbert D. Grover)

Grassland Biome Program

The U.S./IBP* Grassland Biome Program was initiated in 1967. Model development has been an important objective of this project since its inception. Early models (pre-1969) were oriented toward subsystems and processes, whereas later models assumed a "total system" approach. Development of ELM began in 1971. ELM is a nonlinear, differential-equation based model. It logically reflects the experience gained through the development of earlier models and attempts to account for all ecosystem processes using interacting abiotic, producer, consumer, decomposer, and nutrient submodels (Fig. 2.1). One of the more significant innovations arising through the initiation of ELM (according to its designers) was the development of SIMCOMP, a new language developed specifically to facilitate communication among programmers, biologists, physical scientists, and other model contributors (Gustafson 1978).

The objective of ELM was to develop "a total-system model of the biomass dynamics for a grassland that, via parameter change, could be representative of the sites in the U.S./IBP Grassland Biome network (Fig. 2.2), and with which there could be relatively easy interaction" (Innis 1978). The specific questions addressed in the Grassland Biome study included (Innis 1978):

*International Biome Program.

1. What is the effect on net or gross primary productivity as the result of the following perturbations: 1) variations in the level and type of herbivory; 2) variations in temperature and precipitation, or applied waters; and 3) the addition of nitrogen or phosphorus fertilizers?

2. How is the carrying capacity of a grassland affected by these perturbations?

3. Are the results of an appropriately driven model run consistent with field data taken in the Grassland Biome Program, and if not, why not?

4. What are the changes in the composition of the producers as a result of these perturbations?

Figure 2.1 depicts the major compartments considered in ELM-73; however, a general schematic diagram for ELM-77 would not appear significantly different. ELM is divided into eight major submodels: water and temperature flows, plant phenology, producers, mammalian consumers, grasshoppers, decomposers, nitrogen, and phosphorus. Solid line boxes in Figure 2.1 represent state variables in the model. Dashed boxes are meant to denote variables at different levels through a soil profile, different species, functional groups, or different age classes of an organism. Solid arrows between boxes represent flow of material or transformation processes. Dashed arrows indicate influences among components not directly involving mass flow. Carbon, rather than biomass, is tracked through the system because carbon is conserved, whereas biomass can only be accounted for at the level of all elemental components (C, H, O, N, P, etc).

ELM is one-dimensional in that spatial heterogeneity is considered only along a vertical axis (Cole 1976). State variables that are categorized according to aboveground, surface, or various soil horizon components include water, temperature, decomposers, belowground litter, humic materials, and nutrients. Driving variables for ELM include precipitation, maximum and minimum air temperatures, soil temperatures at 180 cm, relative humidity, and cloud cover. A stochastic weather generator has been developed that can provide these driving variables in lieu of real data.

In the general trophic structure of ELM there are no accommodations for birds, reptiles, amphibians, or aquatic organisms (Fig. 2.3). Arthropod consumers are represented only by several genera of grasshoppers grouped as one cohort. Producers are categorized into five functional groups: warm season grasses, cool season grasses, forbs, shrubs, and cacti. Invertebrate detritivores are not included in the decomposition model, as only microbial activity is simulated.

The omission of some important ecosystem components (e.g., invertebrate detritivores) might be expected to weaken the validity of model outputs. Internal compensations due to under- and over-estimations of other producer variables, however, are expected to overcome the impact of such omissions.

The interconnectedness of ELM is considered by its designers as one of its stronger points. This interconnectedness may also provide unpredictable complications in modifying the model by replacement or addition of submodels. To illustrate the complexity of this characteristic of ELM, Table 2.3 lists some interconnecting variables and the number of times these variables interact in a simulation. These points are of special importance in the evaluation of ELM as the framework for a WIPP model.

Abiotic Submodels (Parton 1978) -- The abiotic submodels have been described as the most mechanistic and detailed submodels in ELM because of their reliance on physical principles rather than on biological variables (Van Dyne et al 1977). The submodels comprising the abiotic section are the water-flow and temperature profile submodels.

The water-flow submodel simulates water (precipitation) flow through the plant canopy and soil layers (Fig. 2.4). In this submodel, equations taken from the literature are modified to calculate standing-crop interception as a function of the daily rainfall amount, height of the plant canopy, the fraction of ground area covered by vegetation, and litter interception (a function of daily rainfall and litter biomass). Rainfall that is not intercepted is subject to runoff or soil infiltration. Several system characteristics will determine the relative importance of

runoff or soil infiltration (i.e., precipitation rate, slope, soil type, and infiltration rate). The model simulates infiltration of rainfall that is not intercepted by transferring water in excess of field capacity to successively deeper soil layers until there is insufficient water to bring the next soil layer to field capacity.

Evapotranspiration loss includes evaporation of intercepted water, evaporation from bare ground, and transpiration. Evaporation from standing crop and litter materials is simulated as occurring at the potential evapotranspiration rate, which is determined on the basis of average daily air temperature, relative humidity, cloud cover, and wind speed. Equations estimating bare soil evaporation rates take into account a slowed evaporation rate as topsoil layers begin to dry. The depth to which this kind of water loss will continue is dependent upon soil type, and will subsequently vary from site to site.

Transpiration loss is assumed to occur from all soil layers in which living roots are found. An equation relating leaf area index to bare soil is used to estimate the relative importance of transpiration vs bare soil evaporation.

The temperature profile submodel computes temperatures at 13 points in the soil profile, average maximum air temperature in the canopy, average daytime air temperature at 2 m, and total daily solar radiation. The average daily air temperature, potential evapotranspiration rate, standing crop biomass, and the ratio of actual to potential evapotranspiration rates are the driving variables required.

Driving variables for the abiotic model may be derived from observed climatic data or from a stochastic weather simulator that has been developed for the ELM model. The daily driving variables, daily rainfall, daily relative humidity, cloud cover, wind speed, and maximum and minimum air temperatures at two m, represent one of the more significant changes from ELM-73 (the older version required only maximum and minimum air temperatures and precipitation). Long-term averages may also be used in place of daily variables.

Producer Submodels (Sauer 1978) -- The submodels dealing with primary producers in the ELM model are designed to simulate and integrate plant phenological dynamics and carbon-flow processes. Plant species are categorized as warm-season grasses (e.g., *Bouteloua gracilis*, cool-season grasses (e.g., *Agropyron smithii*), forbs (e.g., *Sphaeralcea coccinea*, shrubs (e.g., *Artemisia frigida*), and cacti (e.g., *Opuntia polyacantha*).

The phenology submodel was designed according to hypotheses relating weather conditions (temperature and moisture) to changes in plant phenology. Figure 2.5 illustrates and describes the seven phenophases modeled. A producer category may, at any given time, be distributed over more than one phenophase. Changes in the distribution of a producer group among phenophases simulate phenological change. The flow between phenophases is dependent upon metabolic rate (which is in turn considered to be temperature-dependent) and upon carbohydrate accumulation (which is positively correlated with the amount of solar insolation). Ten-day moving averages of temperature and insolation values are used in the model in order to simulate a time lag in plant response to environmental conditions.

Phenological change and carbon flow in the real world are largely dependent upon plant-soil water relations. The phenology submodel accounts for these factors utilizing soil depth, soil water content, and root distribution of the respective producer groups as input variables.

In general, optimal temperatures and levels of insolation accelerate phenological change, whereas low temperatures and low levels of insolation slow phenological change. Phenological change occurs when designated temperature and carbohydrate reserve thresholds are surpassed. For example, continued drying can increase flows to the fruiting stage, whereas increased soil moisture can reverse flows from predominantly fruiting to predominantly flowering phenophases.

Senescence and winter quiescence are considered to be sequential phases in adapting to unfavorable conditions that are regularly experienced at or near the end of the growing season. Winter quiescence is ended as favorable conditions return, or following some designated period of time, and is simulated by the transfer to phenophase 2 (see Figure 2.5). Perennials and annuals are treated similarly in the submodel; however, phenophase 1 (winter quiescence) in annuals is represented entirely by seeds.

Figure 2.6 illustrates the paths of carbon flow in the producer submodel. The litter compartments are considered common to all producer groups, whereas shoots, crowns, live roots, seeds, and standing dead compartments are simulated separately for each producer group.

Net photosynthesis is equal to the difference between the gross photosynthetic rate and shoot respiration. Shoot respiration is simulated as a temperature-dependent function of the gross photosynthetic rate. Grazing is assumed to increase shoot respiration and increase the translocation of photosynthate from shoots to roots. This may occur due to trampling by large grazers, as well as to the direct removal of plant material by consumers. In annuals, materials are not stored in roots; therefore, only shoot respiration increases with grazing.

Total insolation available for photosynthesis is divided among producer groups on the basis of leaf area index and their respective proportions of live to dead shoots intercepting light. Shoot growth, and subsequent increases in photosynthetic area, is in part dependent upon the distribution of net photosynthate to live roots, crowns, and shoots. Translocation from shoots to roots is in turn dependent upon live shoot weight, live root weight, soil water potential, nitrogen, phosphorus, phenology, and grazing impact. Translocation rates from shoots to roots is computed to increase with phenological development from early spring to mature stages. This simulates photosynthetic allocation based on rapid shoot growth early in the growing season to peak photosynthetic

area and later storage of energy reserves for winter dormancy. This pattern does not occur in annuals. Following shoot maturation, photosynthate is allocated to seed development.

Seed production is not considered as important for perennials as it is for annuals. Seed growth is regulated by shoot weight (during flowering and fruiting phenophases) and net photosynthetic rate. Seed germination completes the carbon pathway in annuals and is dependent upon soil moisture conditions and temperature.

Producer crowns are modeled as carbonate storage organs. These include stem bases in grasses, woody stems and roots in shrubs, and pads in cacti. These organs provide an energy and organic carbon base for initial spring growth. Translocation from crowns to shoots is a function of soil temperature and crown metabolic rate.

Root respiration is simulated as a function of mean soil temperature in the top 60 cm of soil. Soil atmospheric content is not included in this portion of the model. Root death is dependent upon soil moisture and occurs at a constant rate under moderate conditions, but increases as the soil moisture content decreases below 10% of field capacity.

Mammalian Consumer Submodels (Anway 1978) -- State variables and information, and material flows pertinent to the mammalian consumer submodels are illustrated in Figure 2.7. The two primary impacts of consumers on the ecosystem are assumed to be food intake and waste elimination. Animal densities and metabolic rates are the major control variables in these submodels. These major variables are in turn strongly influenced by air temperature, animal weights, wastes (gaseous, urine, and feces), animal activity, reproductive conditions, population densities, population age distributions, hunger, potential food consumption, food availability or accessibility, food preference, and the digestibility of foods. Values designated for a consumer's metabolic energy requirements, diet preferences, potential food utilization, and biological index (an indicator of overall health and age class) are meant to represent a hypothetical "average" individual for the respective consumer category, group,

or cohort. Birth and death rates, however, are considered at the population level.

The food categories referred to in Figure 2.7 are exploited differentially depending upon the consumer group considered. The model is capable of simulating the population dynamics and trophic interactions of up to ten consumer types; however, only seven have been utilized in the current versions of ELM. These include cow, jackrabbit, coyote, grasshopper mouse, deer mouse, ground squirrel, and kangaroo rat.

The energy requirements of a consumer group is a function of basal metabolism, heat increment, activity, and the energy content of food consumed. In determining an energy requirement for a consumer and the energy content of food, accommodations are made for the metabolic energy required to digest a particular food type. The energy requirement of a consumer is divided by the energy content of food and multiplied by the fraction of carbon in the food in order to estimate the amount of food carbon (kg/day) needed to meet a consumer's energy requirement.

The diet selection of herbivores may have long-range effects on producer species composition or species abundance. In general, consumers will select specific food categories and will prefer early plant phenophases over later ones for a given producer category. Live and dead standing shoots and seeds represent potential food sources from the producer categories. Grasshoppers and small mammals represent potential food sources for predators. Biological indices have been designated for these various food categories to reflect palatability, food quality, and general condition of the food resources.

Daily food intake is estimated using input variables representing consumer food requirements, digestibility of foods consumed, the consumer's food deficit (hunger), food needs of offspring, size class of the consumer, density versus food consumption of consumers, age class of consumers, and food preferences. Producer phenological stage influences large herbivore food consumption, since greater proportions of plant materials from later stages of development may be lost as feces. The

destruction of food by trampling and dropping after harvest is estimated for large herbivores as a constant proportion of the amount of food ingested. A similar factor is used to estimate the amount of prey material that is not consumed by a predator.

The general health of a cohort, or a consumer category, is accounted for by using a biological index that relates the age and weight of the consumers to their respective potential life spans and expected weight for their present age. The birth rate of a consumer is dependent upon environmental conditions, reproductive characteristics of the respective group, and the biological index mentioned above. Photoperiod, temperature, and moisture are important environmental variables with regard to reproduction. Twenty-day running averages are maintained for these factors. The potential number of young per individual and the birth weight of offspring are designated by the modeler by using estimates from field data. In order for reproduction to occur, a threshold value for the biological index must be surpassed.

Mortality is modeled to occur due to old age, starvation, predation, or "other causes" (disease, competition, etc). Death from old age occurs when the remaining members of a cohort complete the designated life span of that species or consumer group. Predation losses are estimated by totaling all flows from a food category consisting of animals. The difference between simulated weight of a cohort from the expected weight is compared to a designated starvation threshold for that consumer group to estimate the number of individuals lost due to starvation. The levels of mortality due to other causes (disease, competition, and other forms of predation) are estimated from field data and incorporated in the model as input parameters.

Grasshopper Submodel (Rodell 1978) -- The compartments and flows simulated in the grasshopper model are illustrated in Figure 2.8. The abiotic variables that influence the activity of grasshoppers include temperature, precipitation, and relative humidity. The phenological development of producers subject to grasshopper foraging is also important

in predicting the impact of this consumer group. Interaction with mammalian consumers may be direct (e.g., predation by coyotes) or indirect (e.g., competition with other grazers).

Figure 2.9 depicts alternative carbon flows in the grasshopper model. The model is not species specific, but assumes that all grasshoppers are present over winter in later nymphal stages rather than as eggs, and that all species respond similarly to the driving variables utilized.

Temperature and rainfall are considered important variables with regard to grasshopper life-cycle dynamics. Temperature influences feeding rates, subsequent developmental rates, the number of eggs laid, and hatching. Soil water influences grasshopper development and also affects food abundance and quality. Food availability, through its impact on mortality and sexual maturation rates, is the only density-dependent factor governing grasshopper population dynamics modeled. Mortality may also occur due to temperature extremes, low humidity, precipitation, predation, and, to an unknown degree, age and fungal or bacterial disease. The influence of disease on grasshopper population explosions are often noted following dry years. In this model, young nymphs are more sensitive to rainfall than grasshoppers at later developmental stages.

Foraging rate by grasshoppers is simulated as a function of age, temperature, and grasshopper density. Nymphs are predicted to consume more material per gram of insect than adults. The number of hours favorable for foraging behavior is derived from temperature data simulated in the abiotic section of ELM.

Dietary preferences are simulated using a composite index that weighs the following factors: (1) the availability of a particular forage category, (2) phenological stages present, and (3) an index reflecting preferences for forage types based on field (Van Horn 1972) and laboratory studies (Mitchell 1975).

Decomposition Submodel (Hunt 1978) -- The compartments and processes simulated in the decomposition submodel are illustrated in Figure 2.10.

Decomposition is represented by flows to active decomposers and respiration by flows to the carbon dioxide sink. Flows from decomposers to substrate represent death of microorganisms. Movement of materials upward in the soil occurs due to mechanical processes (e.g., burrowing activity), whereas downward movement occurs due to leaching. Soil water potential, temperature, and soil nitrogen concentrations are variables that influence decomposition rates.

Inorganic nitrogen availability in the soil is presumed to have a linear affect on decomposition of labile and refractory substrate fractions. Inorganic nitrogen concentrations, however, are only expected to influence belowground decomposition rates, as temperature and moisture are considered the most important exogenous variables active in the decomposition of litter, feces, and humus.

One of the most important features of this decomposition model is the assumption that microbes represent the majority of the decomposer biomass in a short-grass prairie ecosystem. Consequently, only microbes are considered in this model, and it is further assumed that decomposition rates are independent of the size of microbial populations. Thus, provided moderate temperature and moisture conditions, decomposition is substrate-limited. Whenever conditions become too severe to permit microbial activity, or when substrate availability decreases, a designated proportion of the microbial population enters an inactive state. Temperature, soil moisture, inorganic nitrogen concentrations, and substrate availability are key factors in reactivating these microbes.

Nitrogen Submodel (Reuss and Innis 1978) -- Figure 2.11 illustrates the state variables and flows important to the nitrogen submodel. Note that several of the compartments may be simulated at up to four depths in the soil. Exogenous driving variables for this submodel are soil temperature and soil water potential.

Nitrogen flows are simulated as a function of one or more of the following factors: time, soil temperature, soil water potential, daily growth rates for producers, death or decomposition of roots, or soil

nitrogen concentration. Nitrogen inputs to the model include precipitation, fixation by free living organisms, and fixation by symbiotic organisms.

The mineralization rate for soil organic nitrogen is considered a function of soil temperature, soil water potential, and substrate concentrations. Immobilization primarily involves dead root material rather than soil organic material; therefore, a reverse flow between these components is not modeled.

Flows representing nitrogen uptake by live roots, translocation, transfer from shoots to litter, and transfers due to decomposition of litter and dead roots may be determined using driving variables derived from a producer-decomposer submodel within the nitrogen submodel. This submodel is utilized when similar information is not available through integration with the more sophisticated producer and decomposer submodels already discussed.

Nitrogen uptake by live roots is modeled to include nitrate and ammonium forms. Nitrate production from ammonium is modeled as a function of nitrite production, which is a rate-limiting step in this oxidation process. Uptake is considered dependent upon nitrate and/or ammonium concentrations, soil temperature, and soil water potential. Translocation of nitrogen forms allowing uptake is assumed to be controlled by the plant in a manner maintaining a relatively constant shoot/root nitrogen ratio. The ratio maintained, and uptake affinities, are a function of producer phenology and plant growth rates.

Phosphorus Submodel (Cole, Innis, and Stewart 1977) -- The objective of the phosphorus submodel is to simulate phosphorus cycling in a grassland ecosystem using a model that would operate under a wide range of abiotic and biotic input variables. Figure 2.12 illustrates the state variables and flows included in the model. The dashed line in the figure represents the soil surface, so that there are five aboveground state variables, a live root compartment for four soil layers, and six belowground state variables replicated for each of four soil layers. It is

assumed in this model that translocation of phosphorus in plant roots is the only means for vertical upward movement of phosphorus in the soil. Downward movement of inorganic phosphorus due to water infiltration is assumed to be limited, except in sandy soils. The greater downward mobility of organic phosphorus in soils is accounted for in the model.

Phosphorus uptake by plant roots is assumed to occur via the diffusion of water soluble forms only. The supply of phosphorus for roots is maintained by a concentration gradient established in soil water films. Continuous supply of phosphorus in this manner is in turn dependent upon the supply of phosphorus from soluble phosphate minerals, phosphate absorbing surfaces, and organic phosphorus mineralization. Plant root uptake is simulated to move phosphorus from each soil layer to the respective common pools of live root phosphorus that has a constant concentration with depth. Differences in root phosphorus concentration with depth may in turn be dependent upon fractions of live vs dead roots present, relative age of roots, and the proportion of juvenile, nonsuberized, and suberized developmental stages.

Root uptake of phosphorus is an active process in which energy is expended to transport phosphorus across the plasmalemma into individual root cells where phosphorus concentrations may be 50 to 100 times higher than in the adjacent soil solution. Rate of uptake is strongly influenced by plant growth, functioning of plant parts, and phosphorus availability. Other nutrients influence phosphorus uptake through their effect on plant growth processes.

Phosphorus translocation is assumed to be highly dependent upon growth processes and directed towards developing tissues. Phosphorus flow from roots to shoots may only occur when root concentrations are above a designed threshold (0.05% P) and is enhanced only until root phosphorus concentrations reach an upper level of 0.5%. In the event that root concentrations exceed 0.5%, or live shoots are not able to utilize the phosphorus supply due to some other limiting factor, phosphorus may be leaked to the soil.

The largest annual flow of phosphorus in this submodel is represented by microbes and other decomposers. These flow rates are based on estimated seasonal populations of decomposers, turnover rates, and available data on decomposer species phosphorus concentrations. Phosphorus uptake by decomposers is simulated to occur in the same manner as for roots, however, the efficiency of microbes per unit of biomass is 20 times greater than for plants. Values for decomposer biomass are derived from the decomposition submodel. Net decomposer uptake is simulated as a function of microbial biomass, temperature, moisture, and a factor reflecting return flow to the soil.

Mineralization of organic phosphate is modeled to include a stable and a labile pool. These categories reflect the varying susceptibilities of organic compounds containing phosphorus (e.g., nucleic acids, phospholipids, inositol phosphates, sugar phosphates, nucleoprotein) to enzyme hydrolysis. The rate at which phosphorus-containing compounds are mineralized was found to vary with soil depth at some sites (Pawnee), but was constant with soil depth at other sites (Matador). The point is made then that particular attention should be given to the mineralization process when applying this submodel to other sites.

Desert Biome Program

The Desert Biome Program was initiated in conjunction with the other U.S./IBP studies in the late 1960s. Program study sites were subsequently established to represent Great Basin, Mohave, Chihuahuan, and Sonoran desert types (Wagner, 1970). The objectives of the program included collecting data contributing to the understanding of basic energy flows in desert ecosystems, and producing an ecosystem-level simulation model. Ostensibly, the information and model generated would be used to guide future management decisions in desert ecosystems.

Three somewhat different modeling approaches have been utilized during the term of the Desert Biome Program. Prior to 1974, terrestrial modeling efforts were directed toward the development of both general purpose models and question-oriented models.

General purpose models were designed for integration as an ecosystem level model. Various submodels have been developed along this line to represent plant, animal, and soil communities. The submodels for these compartments have been subjected to several revisions designed to increase their respective complexities and/or the length of simulation for which they may be utilized (Goodall 1973). By combining versions of submodels representing the plant, animal, and soil communities, the user can generate an ecosystem model. The ability to interface submodels of different complexities is seen as a positive feature of the Desert Biome model. Investigators concerned specifically with one compartment of the ecosystem (e.g., the soil community) may opt to utilize simpler versions of submodels for compartments that are of indirect importance, and thereby avoid the need to provide detailed data for those submodels (Payne 1974).

Question-oriented models were developed to be independent of one another and have only indirectly contributed to the ecosystem level models. These models were directed toward answering questions such as "What is the wood consumption of a colony of termites?" (Wilkin et al 1975).

In 1974 a new modeling effort was begun that reflects a strong influence of the Grassland Biome Program, i.e., the resulting "water response" submodels were designed to address the following question (Wilkin et al 1975): What effect does increasing or decreasing annual water input above or below the present long-term pattern have on the annual aboveground phytomass at the five validation sites?

The water response models are different from aquatic models. The Desert Biome aquatic modeling effort was designed to produce a predictive model appropriate to several types of aquatic habitats present in desert ecosystems. The types of aquatic systems selected for this modeling effort were permanent springs, standing water, and streams.

The following discussion presents a very general overview of the most advanced versions of the general purpose submodels and the aquatic

submodels. Available publications regarding the water-response models indicate that they are not as highly evolved as are the general purpose models. It is unfortunate that no comprehensive synthesis articles regarding the Desert Biome Program have appeared in the current literature. Goodall's (1975) review of the program may have been intended to satisfy such an objective, but has long been outdated.

Terrestrial Models -- The Desert Biome Terrestrial Ecosystem model is divided into three major components: plant, animal, and soil. The following discussion will deal primarily with state variables and processes. Driving variables are essentially all deterministic, with no stochastic elements apparent to this author.

To provide a framework for integrating the dynamic submodels representing the plant, animal, and soil components, an organizational program is provided (Goodall and Gist 1973). Subroutines within this program (MAIN) calculate values for input variables required by the respective submodels, computes exogenous meteorological variables (EXOGEN), and organizes model output (REPORT and GRAF).

Subroutine EXOGEN is of basic importance to the terrestrial model as many processes are temperature-dependent. In the most recent version of EXOGEN, hourly values for temperature, irradiance, relative humidity, dew point, wind speed, and evaporation rate can be utilized in providing inputs to the respective submodels (Goodall and Robinson 1974).

Plant Processes, Version IV (Valentine 1974) -- The plant submodel is illustrated and described in Figure 2.13. This model consists of nine interacting subroutines: WORK, PHENOL, PHOTOS, RESPIR, TRANSL, DISTRB, MINUPT, DEATH, and KOVER. WORK is a supportive submodel that computes intermediate variables required by the other subroutines.

The subroutine PHENOL accommodates five plant developmental phases: dormancy, germination, leafing-out, vegetation, and reproduction. Phenological flows are dependent upon whole-plant concentration ratios of reserve carbon to total carbon. These variables in turn reflect the

physiological status of the plant and the current environmental conditions (i.e., soil water potential, soil temperature, and daylength). Threshold values designated by plant group for physiological status and environmental conditions must be surpassed before plant development may proceed.

In subroutine PHENOL, all changes are unidirectional with the exception of transfers between the reproductive and vegetative phenophases. This reverse flow is attained when a specified critical ratio of carbon in reproductive organs to total plant carbon is surpassed. Initiation of dormancy occurs when any one value for the environmental or physiological varibles is below some critical threshold.

The subroutine PHOTOS models the rate of photosynthesis (expressed as the mean hourly rate of net carbon fixation during daylight hours) as a function of mean daytime air temperature, mean hourly irradiance, and mean soil water potential.

In the subroutine RESPIR, mean hourly respiration rates are determined for nonphotosynthetic organs over 24-h periods. Respiration in photosynthetic organs is averaged only for dark hours. Carbon release due to respiration (CO_2) is subtracted from reserve carbon pools. Air temperature for aboveground organs, soil temperature for belowground organs, and soil water potential are the driving variables for this subroutine.

The translocation subroutine TRANSL computes the exchange of three carbon forms (protein carbon, reserve carbon, and structural carbon) between four organ types (photosynthetic, reproductive, nonphotosynthetic, and nonreproductive aboveground and belowground tissues) for three plant growth forms (annuals, perennial herbs, and woody plants). Temperature, soil moisture, and donor organ reserve-carbon to total-carbon ratios are the driving variables in the subroutine.

The "Carbon Fractional Dynamics" subroutine (DISTRB) allocates translocated carbon to reserve, protein, or structural components in the recipient organ. Initial reserve vs protein carbon concentrations, as well as nitrogen availability (reflecting the potential for protein

synthesis), are utilized in simulating the allocation of carbon in this subroutine. DISTRB also computes the flow of reserve carbon to protein-carbon forms. This is done by setting a threshold value for the relative concentrations of reserve to protein carbon in an organ. Transfer of reserve carbon to protein synthesis occurs when this threshold is surpassed.

The mineral uptake subroutine (MINUPT) simulates the transfer of nitrogen and ash elements from the soil to plants. Uptake rates are modeled as a function of plant nutrient and carbon concentrations. Removal of plant nutrients from the designated soil horizons occurs at a rate proportional to the relative root biomass for the respective layers.

Organ abscission and death are modeled in the subroutine VDEATH. The rate at which these processes occur is simulated to exponentially increase relative to the time elapsed since the initiation of the phenophase in which organ senescence or maturity occurs. In addition, extreme values for soil water potential, or soil temperature, may be modeled as drought or cold, respectively, and may in turn stimulate organ death and abscission.

Ground cover, by species or by plant group, is computed in the subroutine KOVER. Total carbon in aboveground organs is used as an indicator of the relative cover for a species or plant group.

Animal Processes, Version III (Payne 1974) -- Figure 2.14 illustrates the compartments and processes considered in the animal submodels (Versions I, II, and III). In all of these models, spatial heterogeneity is assumed, and a deterministic approach is taken. As in the plant submodel, carbon is partitioned into protein, fat (reserve), and structural components. The flows between the animal, plant, soil, and decomposition compartments depicted in Figure 2.14 are represented in the model as nitrogen, ash elements, and carbon, although up to six components may be considered in the model. The groups of organisms modeled may be designated according to species, with appropriate age cohorts, or at a more general level (e.g., rodents, invertebrates, birds, etc).

The five sources illustrated in Figure 2.14 are live vegetation, shed seeds, dead organic material, soil organic material, and animals. Animal groups may be categorized by feeding preferences such as herbivores, granivores, detritivores, carnivores, or omnivores. Consumption rates, searching ability, and relative food preferences (each of these varying by season), are the important input parameters for the respective animal groups. Searching ability and food preferences are compensating variables with regard to the amount of food resources that may be consumed in order to approach maximum consumption rates.

The fraction of carbon consumed from a particular compartment is computed by this model, which in turn allows estimates to be made regarding the flow of other chemical constituents. In order to simulate the assimilation efficiency of food resources, each chemical constituent for each animal group is given an index reflecting the proportion utilized vs the proportion excreted by the respective consumer groups. Proteins are further given an index indicating their biological value, which reflects the ability of the consumer to utilize them in protein synthesis.

Animal excretion of nitrogen forms can occur through the production of urea in mammals, or uric acid in invertebrates, reptiles, and birds. Carbon excretion can occur as solid waste, carbon dioxide respired, or in the case of ruminants, methane production.

Four animal growth processes are modeled: fetal tissue growth, juvenile body growth, production of food reserves for juveniles ("milk"), and the production of protective outer coverings ("wool", i.e., sheep's wool, insect exoskeletons, etc). Food availability, specifically protein carbon availability, determines the rate of fetal and juvenile growth and/or survival.

Animal mortality may occur due to predation, parasitic infection, disease, old age, or malnutrition. Predation is accounted for through the food preference indices previously discussed. Death due to nonpredator influences is modeled to occur at constant rates for the respective animal

groups. Dead animal material is divided into soft and hard components, reflecting the rates at which the soil processes modeled decompose the organic materials contributed to this compartment.

In the section of the animal submodel, Version III, simulating reproduction, a maximum number of offspring per adult and a maximum potential birth weight are established for each animal group. Parental malnutrition, however, may result in fewer offspring produced, or the birth of smaller offspring. The gestation period is fixed by the modeler, and birth events for an animal group may occur no more than once each season. Juveniles may also reproduce; fetal growth and immature parental growth may continue simultaneously.

Hibernation and aestivation can be simulated in the animal submodel. Inactive seasons for an animal group are defined by the modeler. During this period, the animals are still regarded as within the system and available to predators. Respiration and death, however, are the only processes simulated for these groups.

Soil Processes, Version IV (Lommen 1974) -- Version IV of the Soil Processes submodel represents an interfacing of four submodels: 1) Soil Processes III (Radford 1973); 2) a model for estimating water, salt, and temperature distribution in the soil profile (Griffin et al 1974); 3) a nitrogen submodel (Parnas and Radford 1974a); and 4) a decomposition submodel (Parnas and Radford 1974b).

Soils III (Radford 1973) represents a descriptive model* of some biotic and abiotic processes in desert soils. Figure 2.15 and Table 2.4 illustrate and identify compartments and processes important to this model.

*Based on previous models developed by Bressler and Hanks (1969), Hanks et al (1971), Bressler (1973), and Nimah and Hanks (1973).

Five chemical constituents (total nitrogen, ash elements, reserve carbon, protein carbon, and structural carbon) may be tracked through the soils model. Standing dead, surface litter, and soil detritus represent the litter compartments considered. Soil detritus may be divided among several soil horizons, the depths of which are designated by the modeler. The water content of the soil horizons, surface water, and snow cover are additional input variables that are important.

The soil water section is based on a one-dimensional general-flow equation that includes a term to represent plant extraction (i.e., transpiration; Nimsh and Hanks 1973). Soil temperature is represented as a function of depth, time, and thermal diffusivity (the ratio of thermal conductivity to heat capacity), which is also dependent upon depth and time (Hanks et al 1971). Equations simulating salt distribution are derived from Bressler (1973). The local concentration of salt in the adsorbed vs solute phase, the presence of a salt sink or source (i.e. due to precipitation, dissolution, or salt uptake), and factors representing diffusion and dispersion of salt in the soil are considered in this portion of the model. The soil is assumed to remain unchanged during the term of the simulation, and salt flow is assumed to be vertical and one-dimensional. Thus, this model is restricted to considering salts that do not interact with the soil. Root distribution is assumed to be continuous among horizons. Plants are considered in their capacity to return water to the atmosphere, but it is assumed that no water is utilized directly by the plants, and none is stored by them. In order to simplify soil temperature computations, soil organic matter is assumed to have a negligible effect and, therefore, the specific heat of the solid soil may be considered static. Also, surface soil temperatures are considered to be the same as the mean daily air temperature.

The nitrogen submodel in Soils IV deals with microbial nitrogen transformations and, to some extent, ammonia volatilization (Fig. 2.16). Nitrogen fixation may occur via symbiosis, heterotrophic microorganisms, and autotrophic microorganisms. Other biological nitrogen tranformations

modeled include the conversion of ammonium (NH_4) to nitrite (NO_2), nitrite (NO_2) to nitrate (NO_3), and denitrification.

The rate at which nitrogen transformations occur is dependent upon changes in microbial populations. Specific population growth rates, environmental conditions in the respective soil horizons, and nutrient availability are factors that influence microbial population dynamics. Microbial death may occur at a designated rate for the respective populations, or may be accelerated due to the lack of essential nutrients, or suboptimal environmental conditions.

Symbiotic nitrogen fixation is simulated as proportional to the biomass of microbial fixers and root carbon, and inversely proportional to soil inorganic nitrogen concentrations. Increases in the biomass of fixers and root carbon are also positively correlated with nitrogen fixation. Organic nitrogen is added to the soil through the death of the symbionts and root host tissue. Symbiotic nitrogen fixation, and subsequent soil enrichment, can occur at any depth in the soil profile, as designated by the modeler.

The activity of heterotrophic nitrogen fixers is limited by the availability of soil organic carbon as an energy source, and inorganic nitrogen. The degree to which each of these factors influence microbial activity, and the subsequent death rate of these populations, is dependent upon soil depth.

Autotrophic nitrogen fixation is attributed to blue-green algae on the soil surface. Irradiance and photoperiod are, therefore, important factors in modeling this process. Growth of the blue-green algal populations is predicted by the plant submodel. The nitrogen submodel utilizes data regarding carbon fixation and growth from the plant submodel to estimate autotrophic nitrogen fixation. As with the previously discussed symbiotic and heterotrophic nitrogen fixation processes, soil enrichment occurs through the death of the blue-green algal fixers.

Ammonia volatilization, conversion of ammonium (NH_4) to nitrite (NO_2), nitrite (NO_2) to nitrate (NO_3), and denitrification are interdependent processes which are modeled separately. Ammonia volatilization is directly proportional to ammonium (NH_4) concentration, pH, and temperature, and inversely proportional to plant cover. Oxidation of ammonium (NH_4) to nitrite (NO_2) can occur in any soil horizon and proceeds at a rate proportional to the growth rate and activity of the respective microbial populations. Conversion of nitrite (NO_2) to nitrate (NO_3) occurs at a rate dependent upon the same variables influencing the oxidation of ammonium (NH_4) except for slightly different pH and temperature optimums. Denitrification proceeds at a rate proportional to nitrate (NO_3) availability, the presence of an organic carbon substrate, temperature, and pH; and is negatively influenced by oxygen availability. Oxygen concentrations are estimated on the basis of soil water potential.

The decomposition submodel (Fig. 2.17) considers the microbial breakdown of standing dead litter, surface litter, animal residues, dead roots, and soil organic matter. Parnas and Radford (1974b) stress the following points in describing this model:

1. The rate of decomposition of any litter type, animal residue, or soil organic matter is proportional to the growth of its decomposers.

2. The organic material being decomposed is characterized by its total concentration of elements of concern, C:N ratio, and difficulty of breaking down.

3. For growth, the decomposers can use organic carbon, nitrogen, and other elements which are part of a particular residue, or any other source of carbon or nitrogen available to that particular biomass of decomposers.

4. One must distinguish between carbon compounds, and carbon-nitrogen compounds in the organic material. The former do not contain nitrogen in the molecular form; the process of mineralization of organic nitrogen and immobilization of inorganic nitrogen are also discussed by Parnas (1975).

Figures 2.17 and 2.18 depict, respectively, the flows of constituents between decomposing materials and modeled components and the general

system envisaged with respect to decomposers. Decomposition is considered to occur in several environmental zones, e.g., designated soil horizons, the soil surface, and above-soil (standing dead). The actual breakdown of organic material may occur externally by physical mechanisms independent of microbial action, thereby contributing materials directly to the soil organic matter compartment, or through microbial activity, which is dependent upon environmental variables (temperature, moisture, etc) and microorganisms biomass. External mechanisms, however, are considered insignificant relative to microbial processes.

The major inputs required by the decomposition submodel include environmental conditions (by environmental zone), concentration of the respective organic materials and their C:N ratios, maximum rates of decomposition for each organic material, and the initial or mean concentration of decomposer biomass. The decomposition submodel computes as output the following variables: decomposition rate, carbon dioxide evolution, mineralization rate, and immobilization rate for each type of organic material present in each environmental zone. As with the nitrogen submodel, the nutrients taken up by microbial populations are made available to other organisms only through the death of the decomposers.

Aquatic Models (Wlosinski 1974) -- In the Desert Biome Aquatic Model, the ecosystem is envisaged as a horizontally homogeneous stretch of water, with sediments below it which may exchange materials from adjacent areas as both inputs and outputs (Wlosinski 1974). The limits placed on the model by assuming horizontal homogeneity are somewhat relieved by the ability of the model to consider successive segments of stream such that the outputs from one segment are the inputs to the next segment. This also mimics streamflow. Variable segment lengths may be accommodated as designated by the modeler. As with the Desert Biome terrestrial models, the various compartments (plant, animal, etc) are represented by submodels of varying complexities. This is seen as an advantage in focusing on any one compartment by utilizing sophisticated submodels for the compartment of interest, and simpler, supportive-type submodels for other compartments.

A set of organizational subroutines are integrated into the aquatic model in a manner similar to that described for the terrestrial model. Subroutine EXTERN provides meteorological inputs, and other exogenous variables, to the process submodels. The data handled by this subroutine includes variables regarding atmospheric and overland-flow inputs to the stream, water withdrawal (evaporation, irrigation), inputs from upstream, and inputs from tributaries. Subroutine PHYSIC (Jeppson 1974), in conjunction with some other supportive subroutines, utilizes inputs from EXTERN to determine the following:

- the average depth of water in the ecosystem,
- the average amount of water in the ecosystem,
- the average water velocity,
- the surface area of the ecosystem,
- the wetted perimeter of the ecosystem, and
- the average width of the ecosystem.

Subroutine MEDIUM is a "bookkeeping" program in that material inputs to the system are computed. This allows the separation of water from allochthonous materials that are handled by the system.

Subroutine Aquatic Animal (Wlosinski 1974) -- Figure 2.19 illustrates the compartments and processes in the Aquatic Animal submodel. The processes simulated include ingestion, egestion, respiration, assimilation, scouring and colonization, mortality, cohort transfer, birth, emergence, and drift. This submodel also deals with heterotrophic microorganisms as depicted in Figure 2.20.

Animal ingestion may involve any suspended or benthic plant, animal, detrital, or microorganismal materials according to predesigned preference and availability factors. Intake by a particular group is a function of the biomass of that group. Temperature, maturity of consumers, and the amount of material available also influences ingestion. Temperature has an indirect effect on growth and assimilation through its direct influence on respiration rates.

The animal submodel also simulates population dynamics, with cohort transfers a function of several alternative variables (i.e., temperature, date, weight, etc). Reproduction may occur at specified times of the year (provided suitable temperature conditions exist), or at some constant rate during periods of favorable temperature. Nonpredator mortality may be fixed for each animal group, with dead organisms contributing to the appropriate detrital categories.

Immigration and emigration by drift may be catastrophic (a function of water velocity) or behavioral (dependent upon population densities and food availability).

Heterotrophic microorganisms (Fig. 2.20) are responsible for the decomposition of benthic and suspended detritus, and dissolved organic matter. The activity of microorganisms on a particular type of detrital material is subject to a preference index similar to that incorporated in the equations describing animal feeding behavior. Mineralization and assimilation by microorganisms occur as a constant fraction of substrate utilization. Microorganisms are subject to scouring and transport as a function of water velocity in the same manner as modeled for catastrophic animal transport.

Subroutine VEGET (Wlosinski 1974) -- Plant compartments and processes are illustrated in Figure 2.21. The processes simulated in VEGET include photosynthesis, respiration, death, leakage, scouring, and colonization. Herbivory and changes in phytoplankton densities due to flow are not considered directly by this submodel.

Photosynthesis is affected by radiation, temperature, space, and nutrient availability. The diminishing intensity of solar radiation with water depth, as well as the influence of shading as a function of population densities (a reflection of competition for space), are considered in the submodel. Temperature has the expected parabolic influence on photosynthesis with optimum conditions represented in the moderate portion of the range. Nutrient availability is determined on the basis of summed

requirements for all species present. Photosynthesis is inhibited when a required nutrient becomes depleted and becomes limiting.

Plant mortality occurs at some constant rate characteristic of the particular plant group, or due to extreme temperatures. Temperature "deaths" are converted to overwintering propagules reflected as a decrease in biomass to some level representing the overwintering or dormant forms. Leaching of materials from plants to the aqueous environment (leakage) is simulated as a property characteristic of the plant group and occurs at a rate specified by the modeler.

Sessile plants (attached algae or rooted angiosperms) are subject to being "uprooted" as a function of water velocity. Water velocity also influences colonization of these plant types as some moderate range of water movement during the appropriate reproductive period must be in effect to permit dispersion and reestablishment of propagules. Plants that are washed away enter the suspended detritus compartment. Propagules that are washed away during the reproductive period and remain viable may attach and establish themselves downstream following these events.

Application to WIPP

Development of a site-specific model for the WIPP ecosystem would be a major effort that is not now within the scope of the WIPP Biology Program. Should a model be generated in the future, the aquatic portion of the Desert Biome general purpose model, and the Grassland Biome model (ELM) would provide the basic frameworks for initial WIPP modeling efforts.

Model objectives are seldom stressed sufficiently. Indeed, this is the weakest point regarding the Desert Biome general purpose models, and perhaps the strongest feature of ELM. A viable modeling strategy must begin with a clear statement of model objectives, expressed as a list of model specifications. The properties of the model and the uses for which

the model is designed are described by these specifications. A useful outline to follow in the development of a modeling strategy is as follows (Overton 1977):

1. Specify the model objectives as a list of model specifications.
2. Identify submodels and subobjectives.
3. Construct and validate submodels.
4. Assemble the submodels into the complete model and validate.
5. Seek answers to the objective question.
6. Examine the general behavior of the model; identify behaviors of interest.
7. By sensitivity analysis, identify the structure and parameters that are causal for the behaviors of interest.
8. Validate those causal structures and parameters.

It is doubtful, however, that either ELM or the Desert Biome general purpose models, taken individually, could simulate ecosystem dynamics at the WIPP site with an acceptable degree of resolution. A great deal of original model development, in addition to extensive modification and synthesis of existing models, would be required to model WIPP adequately.

Fundamentally different philosophies were maintained by the Grassland and Desert Biome Programs in the development of the models discussed in this chapter. The Grassland Biome Program emphasized practical objectives involving rangeland management, whereas, the objectives of the Desert Biome Program were not as strictly defined. Perhaps as a result of its management potential, the Grassland model (ELM) received considerable attention and has been identified as the most advanced of the US/IBP models (Watt 1975). It is likely, however, that the level of integration developed among ELM submodels, which is in turn responsible for the model's high degree of resolution, would prohibit the modifications necessary for its application to the WIPP site.

A summary of some points concerning ELM which are relevant to the WIPP project are as follows (Woodmansee 1978):

1. Spatial heterogeneity is not considered in ELM. This deficiency applies to producers as well as consumers.

2. Since an average square meter of prairie is modeled, plants are considered to compete for light as if they are uniformly distributed, which ignores the competitive effects of clumping.

3. Forbs are considered as a single functional group, which ignores the possible importance of cool vs warm season species.

4. Energy flow through birds and reptiles is considered to be unimportant; therefore, they are not included in the model.

5. Grasshoppers are the only arthropod consumers modeled; however, the collective impact of other arthropods is considered implicitly in the modeled response of primary producers.

The developers of the Desert Biome general purpose models consider the option to integrate submodels of varying degress of complexity and resolution to be its strongest feature. The Desert Biome models have been applied to desert ecosystems around the world, however, no recent articles have been found that would verify the success of these efforts. There are no current reviews of the Desert Biome models that identify specific weaknesses.

An accurate and reliable analysis of existing models relevant to WIPP would require the direct involvement of principal investigators in their respective fields of interest. The purpose of this report has been to provide a common frame of reference for all persons involved in the project. Although full-scale modelling of WIPP is not planned, the organization of data as outlined above should promote development of a sound and meaningful monitoring program.

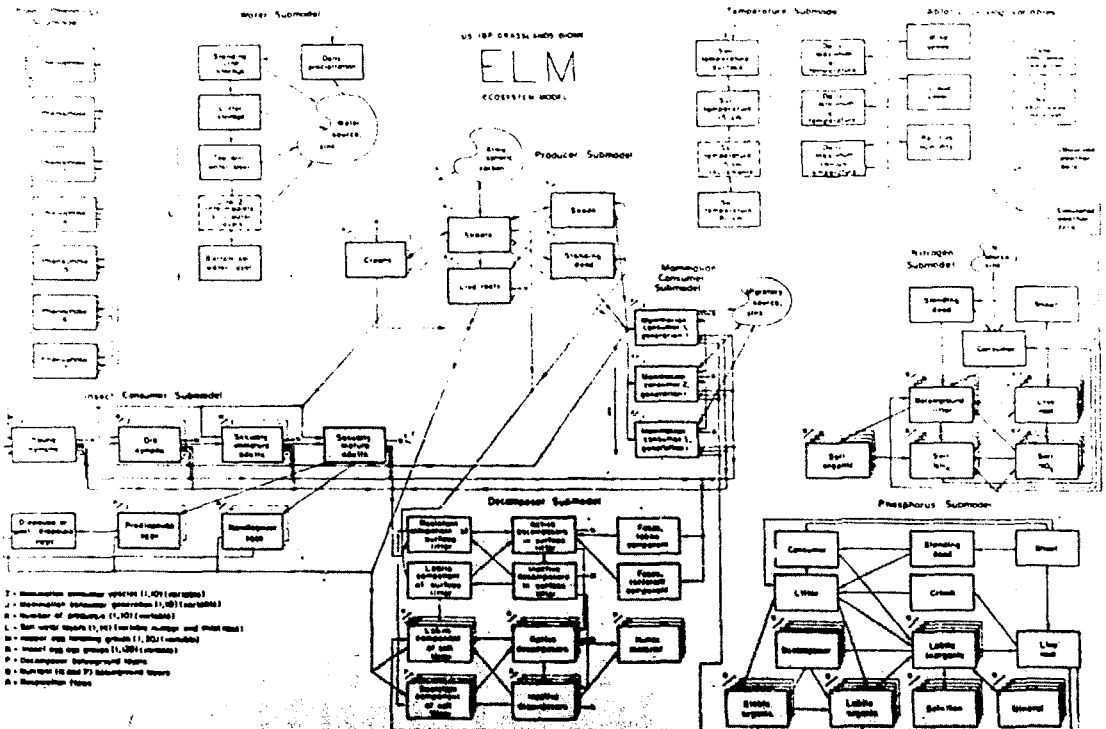


Figure 2.1. Flow diagram for the total ELM ecosystem model (Cole 1976).

ALE	Shrub steppe	Sauer
Cottonwood	Midgrass prairie	Rodell
Jornada	Desert grassland	Anway
Osage	Tallgrass prairie	Parton
Pantex	Shortgrass prairie	Hunt
Pawnee	Shortgrass prairie	ALE
San Joaquin	Annual grassland	Woodmansee

Figure 2.2. Sites in the US/IBP Grassland Biome study, grassland type, and the postdoctoral fellow who worked at each of the sites (Innis 1978).

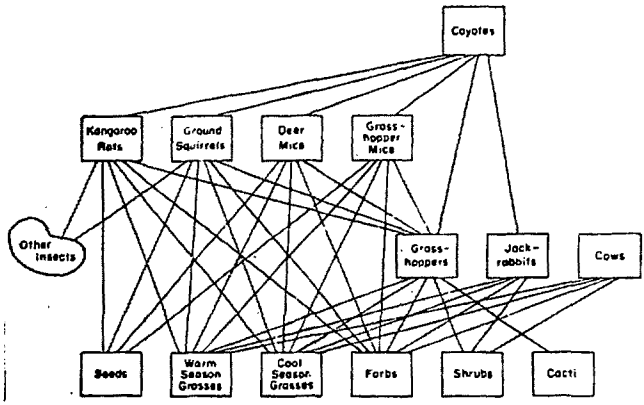


Figure 2.3. Biophagic pathways in ELM. "Other insects are entered nonmechanistically (simply as a function of time) to provide a food source for insectivorous small mammals" (Cole 1976).

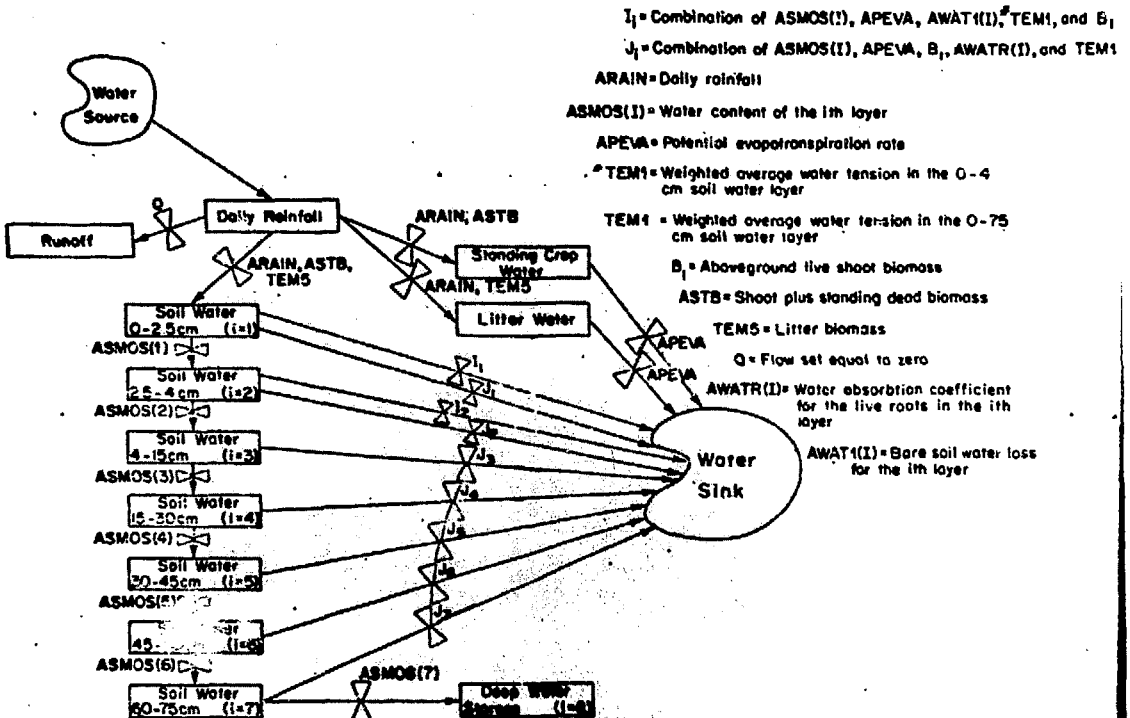
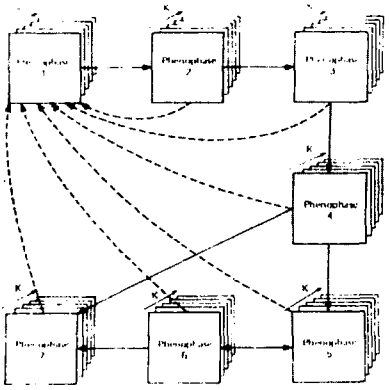


Figure 2.4. Flow diagram of the water flow submodel (Cole 1976).



Definitions:

1. Winter quiescence or first visible growth
2. First leaves fully expanded
3. Middle leaves fully expanded
4. Late leaves fully expanded; first floral buds
5. Flowering (floral buds, open flowers, and ripening fruit)
6. Fruiting (buds, flowers, green and ripe fruit, and dispersing seeds)
7. Dispersing seeds and senescence

Figure 2.5. State variables and flows in phenology model (dashed lines indicate senescence-ending flows) (Parton 1978).

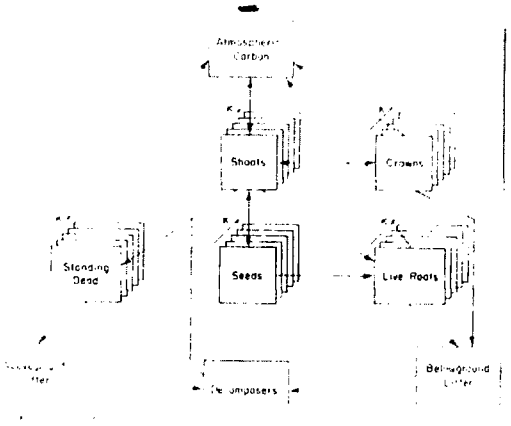


Figure 2.6. Primary producer carbon flow diagram (all compartments are species-specific except the dead-root and litter compartments common to all producers) (Sauer 1978).

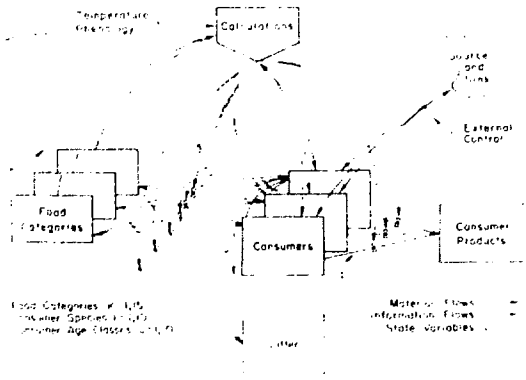


Figure 2.7. Information flows, material flows, and state variables considered in the mammalian consumer model (Anway 1978).

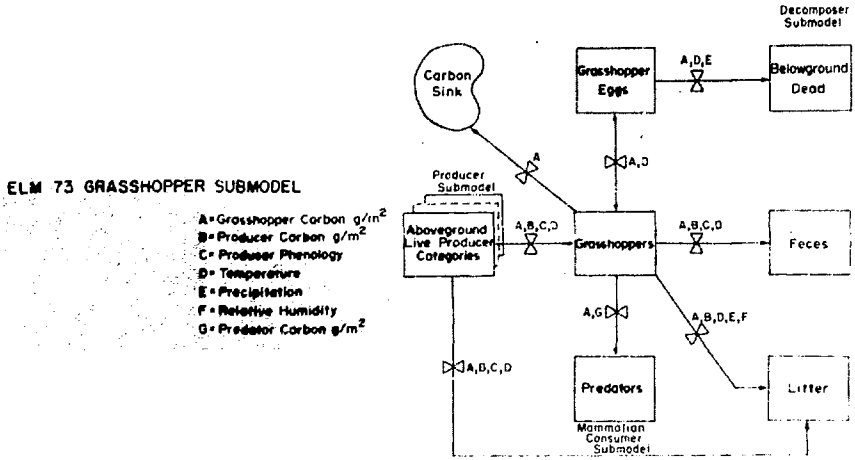


Figure 2.8. Flow diagram of grasshopper submodel and the interactions with other submodels (solid lines indicate carbon flows: A - G represent factors influencing flows) (Rodell 1978).

Figure 2.9.

Flow of carbon through components of a grasshopper population (Redell 1978).

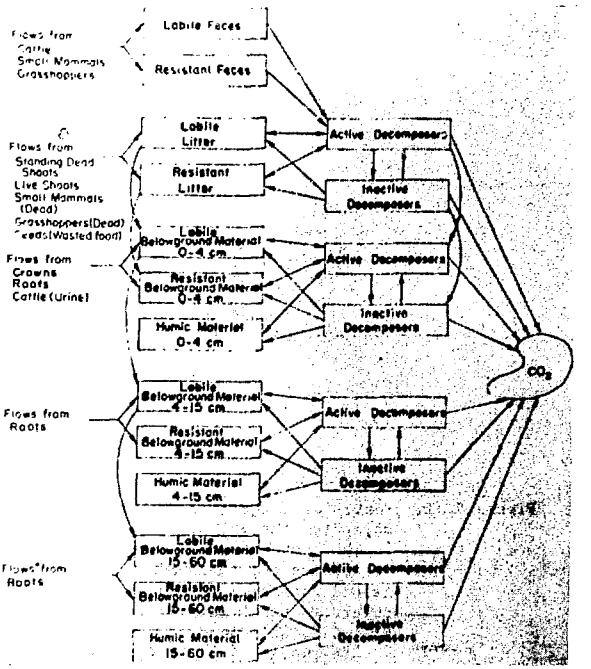


Figure 2.10.

Compartment diagram for decomposition submodel of ELM (Hunt 1978).

Figure 2.11. Basic flow diagram for model simulating nitrogen flow in a grassland ecosystem (Reuss and Innis 1978).

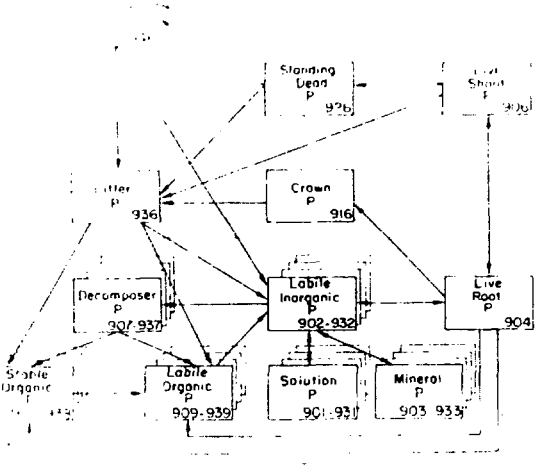


Figure 2.12. Forrester diagram of the phosphorus submodel: dashed line separates the belowground from the aboveground compartments: in the state variable designation the first digit, (9), identifies the P submodel, the second digit in the below-ground variables refers to the soil layer, and the third refers to the P form or location [i.e., the figures 902, 912, 922, and 932 designate the amounts of labile inorganic P (last digit of 2) in the first to fourth soil layers (second digits of 0, 1, 2, 3, respectively)] (Cole et al 1977).

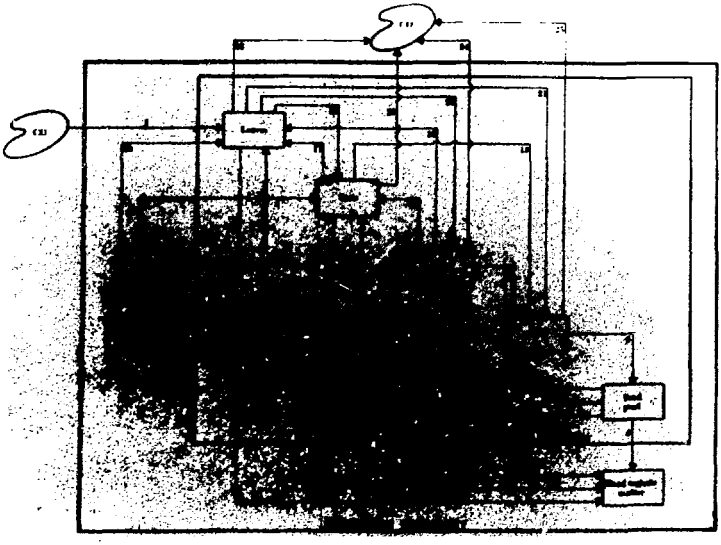


Figure 2.13. Flow diagram for Version IV plant submodel (Valentine 1974).

Processes represented by the arrows in figure above (Valentine 1974).

Arrow	Process
1	photosynthesis
2-6	organ abscission and death, including seed shedding
7-10	mineral uptake
11-13	germination
14-16	leafing out of perennial herbs
14, 16-18	leafing out of woody perennials
19-21	translocation from leaves to other organs during vegetative and reproductive stages
22-25	respiration

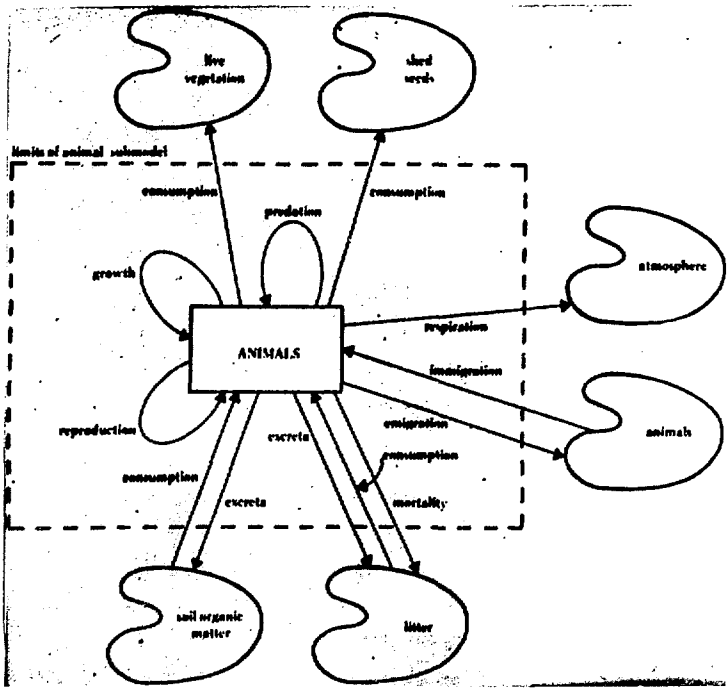


Figure 2.14. Processes in the animal models (Payne 1974).

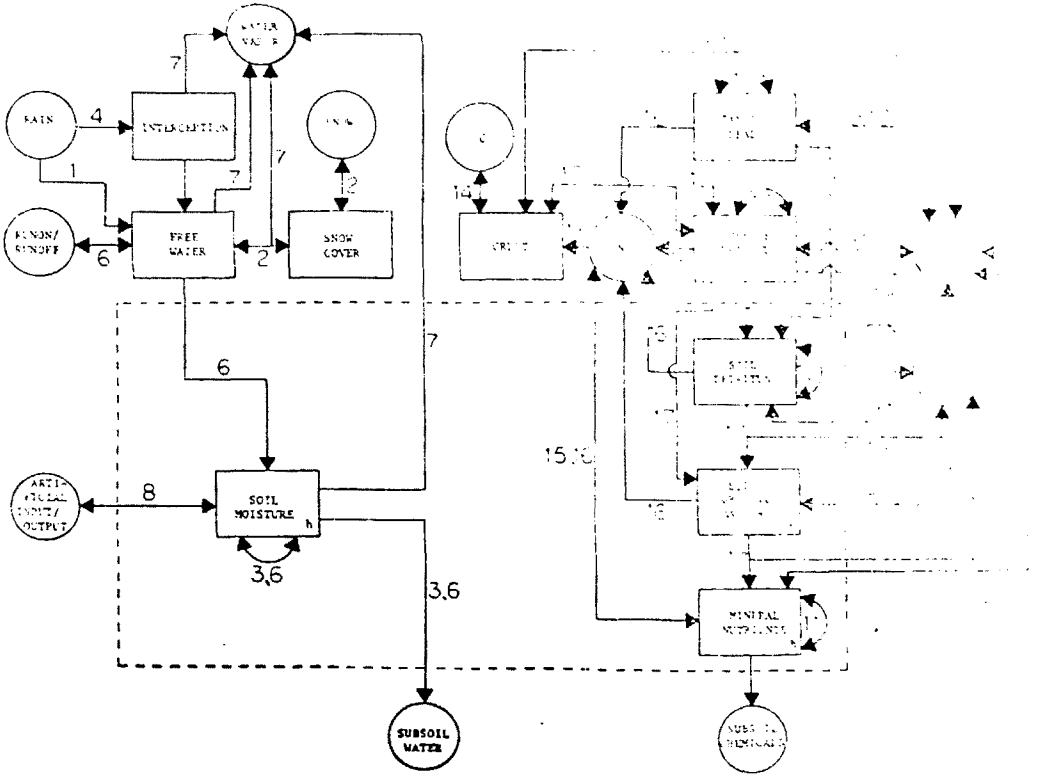


Figure 2.15. System diagram for soil submodel version III (Radford 1973). (See Table 2.4.)

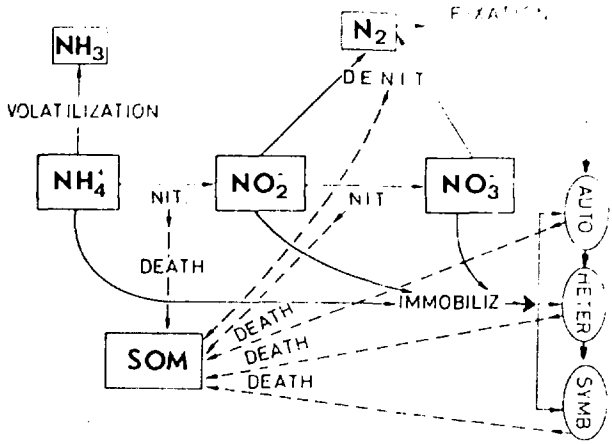


Figure 2.16. Decomposition submodel with connecting flows to related submodels (Lommen 1974).

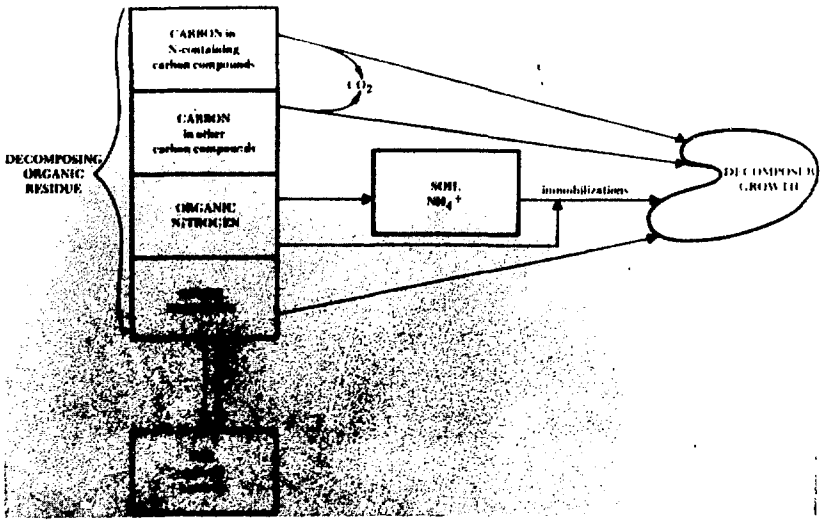


Figure 2.17. General flows of constituents in the decomposition submodel (Parnas and Radford 1974b).

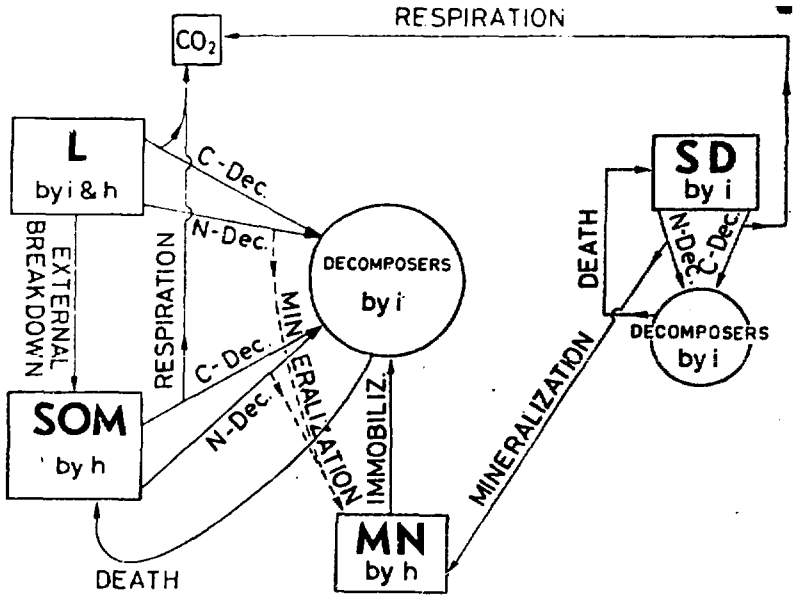


Figure 2.18. System diagram. Note that surface litter and/or standing dead with soil affect only horizon 1. Decomposers of the top horizon normally work on all types of surface litter; each standing dead type has a separate decomposer type "k". The generally physical-mechanical transfer of standing dead to surface litter (as well as a number of other processes) is handled elsewhere (Parnas and Radford 1974a).

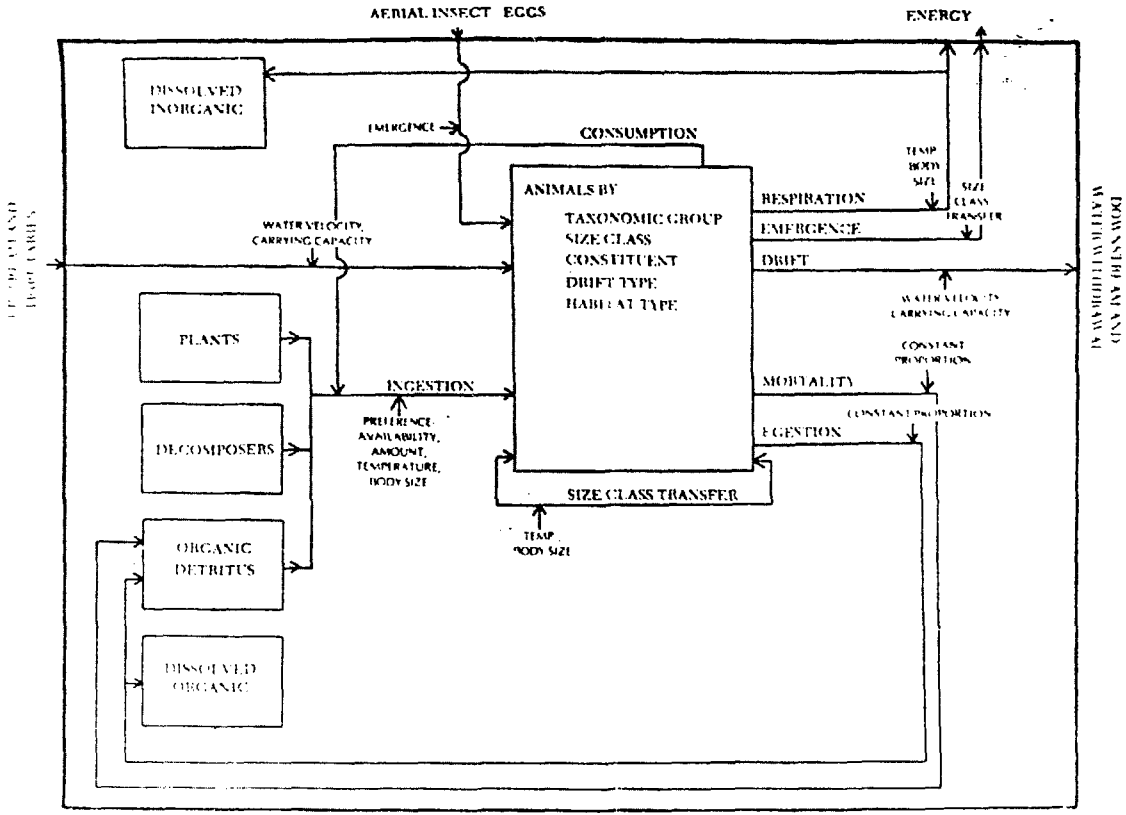


Figure 2.19. Generalized flow model of animal processes (Wlosinski 1974).

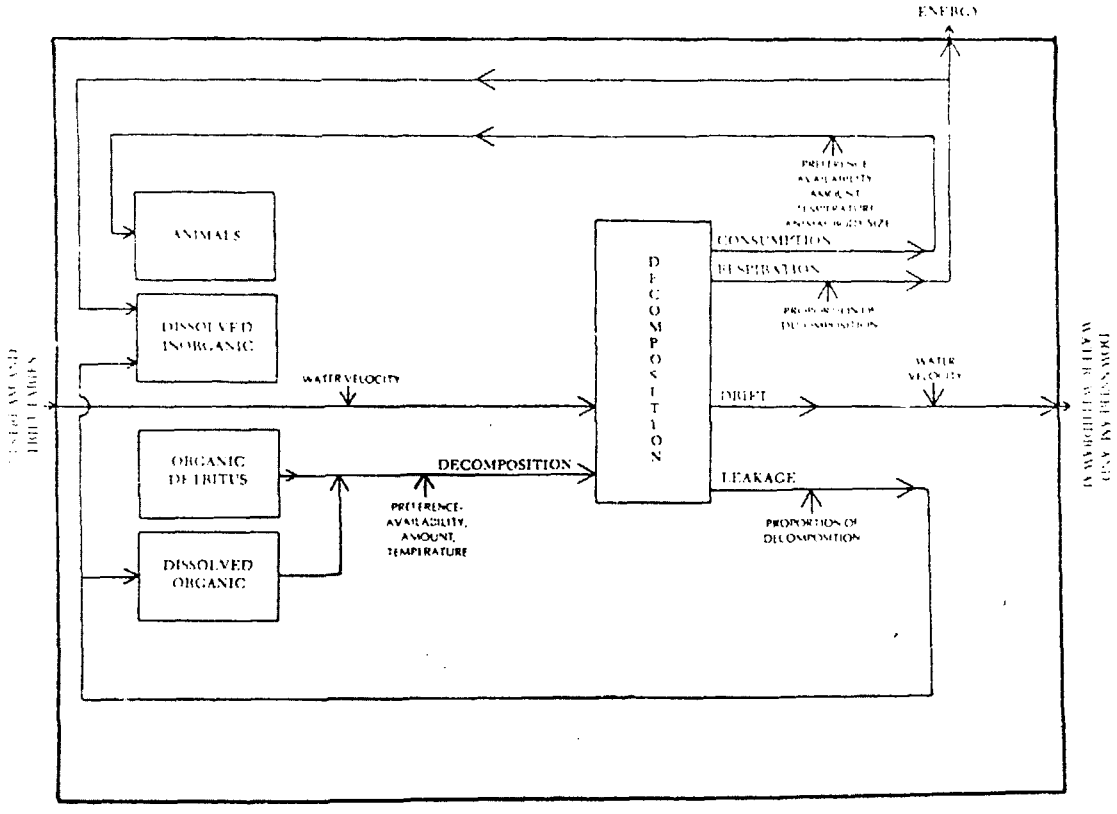


Figure 2.20. Generalized flow model of heterotrophic microorganisms (Wlosinski 1974).

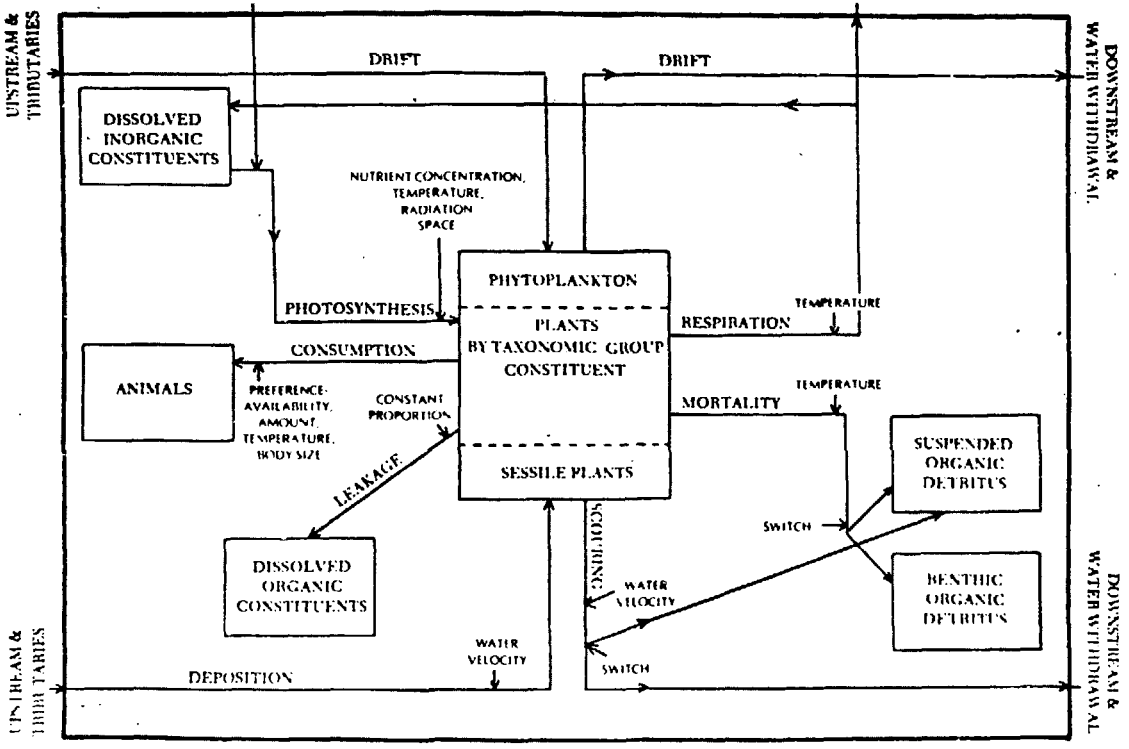


Figure 2.21. Generalized model flow chart of plant processes (Wlosinski 1974).

Table 2.3. Number[a] of variables defined in one submodel and used in another (Cole 1976).

	Defined									
	Temperature profile	Water flow	Producer (carbon flow)	Producer (phenology)	Mammal	Grasshopper	Decomposer	Nitrogen	Phosphorus	Sum
Temperature	--	4	2	0	0	0	0	0	0	6
Water flow	2	--	2	0	0	0	2	0	0	6
Producer (carbon flow)	3	5	--	4	1	1	0	1	1	16
Producer (phenology)	2	1	3	--	0	0	0	0	0	6
Mammal	1	0	4	3	--	1	0	0	0	9
Grasshopper	3	3	2	2	2	--	0	0	0	12
Decomposer	3	9	2	0	0	0	--	6	0	20
Nitrogen and Phosphorus	1	5	8	1	7	1	6	--	--	29
Sum	15	27	23	10	10	3	8	7	1	104

[a]Variables replicated by depth or by species are counted only once.

Table 2.4. A listing of soil processes as labeled in Figure 2.15.

1. Exchanges of water with the environment.
2. Snow melting, snow blowing.
3. Liquid water flow in the soil, excluding infiltration.
4. Rainfall interception.
5. Soil freezing.
6. Infiltration, runoff.
7. Evaporation, transpiration.
8. Artificial input/output.
9. Deposition.
10. Erosion via wind and water.
11. Mineral nutrient flows between horizons.
12. Transformation between detritus types.
13. Limits on all biological activity, notes on rates of change.
14. Crust growth.
15. Nitrogen fixation.
16. Nitrogen losses.
17. Decomposition of detritus to soil organic matter.
18. Decomposition of soil organic matter to mineral nutrients.
19. Respiration of decomposing carbon.

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CHAPTER 3

FLORISTICS OF THE LOS MEDAÑOS WIPP STUDY AREA*

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Introduction

The Los Medaños study area is located in the northern extension of the Chihuahuan Desert which extends in a north-south direction from southern Zacatecas, Mexico, to southwestern Texas, central New Mexico, and southeastern Arizona, mostly at elevations below 4,500 ft (1,370 m). The northern part of this desert region is largely composed of broad table-lands, bajadas, and valley floors of various types of desert grasslands or desert-shrub vegetational patterns.[1]

Conspicuous features of the Chihuahuan Desert are the many, often extensive, ranges of mountains, oriented in a roughly north-south direction. In New Mexico, the most prominent of these desert mountain ranges are the Guadalupe, Organ, and San Andres mountains. Also prominent are the white-crusted salt sinks formed from many thousands of years of alternating periods of inflow and evaporation of salt-laden runoff water in shallow, ephemeral, undrained basins. These deposits are often of considerable thickness.[1]

The vegetation of the northern extension of the Chihuahuan Desert can be characterized by a number of indicator species including creosotebush

*A more detailed presentation of this data can be found in the Annual Report of Biological Investigations at the Los Medaños Waste Isolation Pilot Plant (WIPP) Area of New Mexico for FY1978. Eds. T. L. Best and D. W. Jackson. Report submitted to Sandia Laboratories, Albuquerque, New Mexico. Sandia Contract Nos. 05-7862, 07-1489, 07-8239, 07-9252, and 13-0806. 1500+ pp. Copies of this report are available at the Sandia Laboratories WIPP Archives, Albuquerque, NM.

(Larrea tridentata) on dry plains and slopes between 3,000 (914 m) and 4,500 ft (1,370 m) elevation; tarbush (Flourensia cernua), usually occurring with creosotebush; mescat acacia (Acacia constricta); catclaw acacia (Acacia greggii) on dry plains and slopes; mesquite (Prosopis spp.), often on dunes or along gravelly washes; lechuguilla (Agave lechuguilla) on limestone soils; Wheeler's sotol (Dasylirion wheeleri) on dry rocky slopes and mesas; graythorn (Condalia lycoides); squawbush (Condalia spathulata); palmilla (Yucca elata); bisnaga (Echinocactus wislizenii); Christmas cactus (Opuntia leptocaulis); and ocotillo (Fouquieria splendens).[1-5]

Objectives and Methods

The objectives for 1978 were as follows:

1. to establish study plots in both intensive and extensive areas
2. to provide a floristic checklist of all taxa collected during 1978
3. to make voucher specimens of collected specimens
4. to analyze the vegetation on the basis of density, cover, and frequency in study plots
5. to collect phenological data
6. to develop a vegetation map of dominant taxa
7. to collect mature seeds for seed reference collection and studies of seeds of desert annuals
8. to collect aboveground vegetative biomass material for selected taxa and
9. to collect reproductive biomass material from selected taxa

The Los Medaños site and extension to the Livingston Ridge area covers approximately 100 square miles in Eddy and Lea counties. For a study area of this size, it is essential that the study plan be designed

for an efficient method of collecting vegetational data. Another very significant area of study is the ERDA 9 area surrounding the ERDA 9 site. This four-square-mile area in the west central part of the dunes section has a high probability of being disturbed considerably in the relatively near future.

For accurate reference purposes, an enlarged map (Fig. 3.1) of the entire study area was initially divided into a square-mile grid system, then further divided into a grid of one-hectare (ha) units. Using this grid system, plants collected at any location within the site can be accurately referenced as to location and soil type. Soil-type data for the area from the U.S. Bureau of Land Management and the U.S.D.A. Soil Conservation Service were used.[6,7] Roads and other reference points were also shown on the map.

During the spring and early summer of 1978, 31 study plots were established to obtain floristic and baseline vegetation data. The study plots were selected from widely scattered points throughout the study site to represent the differences in topography and soil types. A stratified random sampling system similar to the Bourdeau[8] and Oosting[2] systems provided a reliable basis for random sampling as well as the desirable characteristics of systematic sampling.

The study plots were established along two main roads: the "north-south road" and the "pipeline road" (Fig. 3.1). The pipeline road runs diagonally across the study site from northeast to southwest. Using the intersection of these two roads as a starting point, eight transect intersect points were established, an average of one mile apart, from north to south along the north-south road. From these starting points, transects were laid in with a transit in an east-west direction and across the contours. Along each line, potential plot locations were established at 1-km intervals. The location of each sampling plot on either side of the north-south road was randomly selected for each transect, thus the study plots are so arranged that no two study plots are located directly opposite each other along the north-south axis.

General floristic studies of the Los Medaños site were begun in February when the first desert annuals began to flower but baseline studies of the plots began in early June, when a large percentage of the plants were in the active growth stage. Baseline data were collected until the middle of September.

The following data were provided by the study plots: checklist of taxa, life form, density, frequency, cover, onset and span of flowering, time of fruit maturation, onset of vegetative growth. After each plot was initially assessed for different taxa and collections were made, the vegetation was studied in the following manner:

1. Each hectare plot was divided into 10 transects 10 m wide and 100 m long; each transect was divided into 10 quadrats, each quadrat 10 m square.

2. Two transects were randomly selected from the initial 10 transects and from each of these two transects a single 10-m-square quadrat was randomly chosen for detailed study.

3. The vegetational cover and frequency in each quadrat was studied by the line-intersect method. Ten line transects equidistant apart were established across the quadrat. The cover and frequency data obtained from these transects was converted to values per hectare. Density values were obtained by averaging direct counts of taxa in two randomly selected plots 1 m x 10 m in size.

Representatives of taxa obtained from the study plots and other areas throughout the Los Medaños site were tentatively identified and placed in plant presses for drying. Location and other pertinent observations were recorded for each specimen. Location data were later coded by map coordinates.

The drying plants were returned to the University of New Mexico Herbarium laboratories for final processing and ultimate storage in insect-proof specimen cabinets. Final processing includes definitive confirmation of identification, determination of potentially threatened or endangered status (in either national or state lists), mounting on permanent-type herbarium mounting paper, application of specimen labels

to the mounting sheet. The specimen labels contain the following information: family name, scientific binomial, authority, common name (if known), precise location, soil type, floristic association, collector, collection number, and date of collection. The specimens are finally given an accession number, vouchered, and stored.[4,9,10]

Other collections of taxonomic and/or reference nature begun in 1978 included seed samples from floristic collections. Seed samples were either taken from plants in the general collection or sampled directly from the field along with the specimen from which they were taken.

After drying, seeds were stored in cabinets provided for the seed collection in the herbarium laboratories. Seeds are kept at a relatively constant temperature in insect-proof vials and cross-referenced with the seed voucher specimen.[11-13] Seed reference samples will be used in studies of seed morphology and as a basis for the confirmation of seed material taken from cheek pouches or stomach contents of various animals using plants in their diet. Other seed collections were mass samples of seeds of desert annuals, to be used after ripening in studies of seed viability.

Results

ERDA 9 Area

Partly because of the relatively small area included in the ERDA 9 study site, about 4 sq. mi. (1036 sq. ha), the vegetation tends to be somewhat more uniform than in other areas. The vegetation of the ERDA 9 study area should be regarded primarily as a floristic association of the following specimens based on average cover and density values: Havard (shinnery) oak (*Quercus havardii*), sand sagebrush (*Artemisia filifolia*), and dune yucca (*Yucca campestris*). Mesquite (*Prosopis glandulosa*), a very obvious dominant in other areas at the Los Medaños site, is not a prominent part of the vegetation of the ERDA 9 area. Although all study sites in the ERDA 9 area are represented by only 7 to 35 plants of *P.*

glandulosa per ha, these plants appear to be in good growth condition and do not seem to be less vigorous than in other areas.

Quercus havardii is by far the most successful shrub in the ERDA 9 area, often forming very dense stands and regularly reproducing by root sprouts. Thus, many of these oak stands are probably of the same genotype. This plant is typically a low shrub, usually not more than 1 m tall in the Los Medaños area, and in mature condition tends to produce at least a small crop of acorns each year. During the growing season of 1978, very few mature acorns were noted; apparently the extremely dry spring at the usual time of flowering inhibited the formation of pistillate flowers. Even staminate catkins were not much in evidence and tended to dry up before the flowers matured.

Among the subshrubs, only sand sagebrush (A. filifolia) is relatively common throughout the ERDA 9 area. Surprisingly, snakeweed (Gutierrezia sarothrae), although occurring sporadically, provided no significant density or cover at any of the study sites in the ERDA 9 area except in the ERDA-S.E. section where Gutierrezia was relatively scattered and not a dominant phase.

Annuals were especially abundant throughout the ERDA 9 area. In terms of density, the most common annuals at nearly all study sites were bindweed heliotrope (Heliotropium convolvulaceum), bluets (Houstonia humifusa), and fetid marigold (Pectis angustifolia). Although Pectis was absent from our study plots at the time the transects were run, all sites should have produced significant stands of Pectis later in the growing season and after the summer rains.

The most abundant grasses at the time of the transect studies were species of three-awn (Aristida) with purple three-awn (Aristida purpurea) the most common in significant densities at all sites, black grama (Bouteloua eriopoda), widely occurring in the intensive area but absent from ERDA-S.E. and ERDA-S.W.; false buffalograss (Munroa squarrosa), apparently the most abundant of all grasses at the site with as many as 301,000 plants occurring per ha; and species of dropseed (Sporobolus)

which were mostly in immature form until rather late in the growing season. Species of muhly (Muhlenbergia) occurred sporadically and late in the growing season, and purple sandgrass (Triplasis purpurea) also appeared.

Data pertaining to the eight individual study sites in the ERDA 9 area are presented in comparative form in Tables 3.1-3.3. Computer-generated maps of vegetative cover for selected taxa are shown in three-dimensional configurations of selected taxa (Figs. 3.2-3.5) and one-dimensional configurations for these taxa common throughout the entire study site (Figs. 3.6-3.23). The entire area was collected for checklist and phenological data several times during the growing season. All taxa collected and identified in the ERDA 9 area are shown in Table 3.4.

Extended Area

As might be expected, the floristic composition of the extended area is much more heterogeneous than that of the ERDA 9 area because of the availability of a great many more habitats. The extended area contains the dry upper mesa with its dense clay soils and underlying limestone bedrock. Here the flora is more typical of the desert grassland association, the most common shrub composition being P. glandulosa. Among the subshrubs, G. sarothrae is most abundant with more than 34,000 per ha and more than 10% cover. Because of the very dry winter, spring, and early summer, most plants in the mesa area were stunted and Gutierrezia, for example, did not begin active growth until at least mid-July. The only yucca in evidence on the mesa is Torrey yucca (Yucca torreyi), a plant which does not exist in the dune plains below the mesa but which occurs, at least locally, at sites in the flats below Livingston Ridge near the western margin of the Los Medaños study area. Y. torreyi is scarce on the mesa. Cacti are relatively common, especially varieties of prickly pear (Opuntia phaeacantha) which is scattered throughout the mesa region at an approximate density of 50 plants per ha. Due to the drought, many of the opuntias were in poor condition and the fruit set was sparse. Approximately 10 to 15% of these plants appeared to be dying back.

Of course, grasses are a very prominent component of the vegetation on the mesa, most common which are B. eriopoda, bush muhly (Muhlenbergia porteri), ring muhly (M. torreyi), burrograss (Scleropogon brevifolius), and fluffgrass (Tridens pulchellus). Dwarf holly (Perezia nana), though not particularly abundant, was more common on the mesa than in most other localities. The entire mesa area showed considerable disturbance from heavy grazing pressures. The mesa area can best be described as a P. glandulosa-G. sarothrae-O. phaeacantha association.

The mesa area drops off abruptly to form a severely eroded, rather steep declivity, at the base of which the vegetation changes markedly in composition as the soils change, first to a gravelly outwash area, then to the low stabilized dunes which cover most of the central area and extend toward Livingston Ridge to the west.

In the extreme northcentral section, there are large active dunes, and south of the James Ranch Headquarters, a series of active dunes extend from east to west. The vegetation of these dunes includes stands of a small tree, Drummond soapberry (Sapindus drummondii), the perennial herbs, snowball sandverbena (Abronia fragrans). species of unicornplant (Proboscidea), and the annual, Reverchonia arenaria. All of these except Reverchonia are of widespread but sporadic occurrence at the Los Medaños site.

Throughout the rest of the central area, certain shrubby dominants tend to prevail, primarily P. glandulosa, O. havardii, G. sarothrae, A. filifolia, and Y. campestris. In certain study sites, all of these taxa are present; in other sites, one or more are either missing entirely or are very low in density. Apparently because of differences in soil type, there were differences in relative density and cover of these shrubby dominants. The dominant importance based on relative cover in the central dunes sites is as follows:

Location	Association
ha 2(A3)	Quercus-Prosopis-Yucca-Artemisia-Gutierrezia
ha 3(C4)	Quercus-Artemisia-Yucca-Gutierrezia
ha 4(D6-1)	Quercus-Artemisia-Yucca
ha 5(E4)	Prosopis-Gutierrezia-Yucca-Artemisia-Opuntia
ha 6(E6)	Quercus-Artemisia-Yucca
ha 7(F3)	Quercus-Prosopis-Artemisia-Yucca
ha 9(I4)	Quercus-Prosopis-Artemisia-Yucca
ha 10(I6)	Prosopis-Gutierrezia-Yucca
ha 18(A7)	Gutierrezia-Prosopis-Artemisia
ha 20(D6-2)	Quercus-Artemisia-Yucca-Prosopis
ha 21(E2)	Prosopis-Yucca-Quercus-Artemisia
ha 22(J7)	Quercus-Artemisia
ha 28(G2)	Quercus-Artemisia-Yucca-Prosopis
ha 29(E8)	Quercus-Yucca-Prosopis
ha 30(C6)	Quercus-Artemisia-Yucca
ha 31(B1)	Gutierrezia-Prosopis-Yucca-Artemisia

Grasses are very abundant in the central dunes area. The severe winter and spring drought no doubt reduced grass cover significantly and many grass taxa were slow in the initiation of growth. There was probably no reduction in the number of species occurring, however. The most common of the perennial grasses were A. purpurea, found in the majority of sites; red three-awn (Aristida longiseta); sand dropseed (Sporobolus cryptandrus); giant dropseed (Sporobolus giganteus); B. eriopoda; hairy grama (Bouteloua hirsuta); fall witchgrass (Leptoloma cognata); Cenchrus incertus, usually locally abundant in the more sandy situation; paspalum (Paspalum setaceum); and bristlegrass (Setaria leucophila). Species of Muhlenbergia were uncommon or absent in the central dunes area, becoming more in evidence in the denser soils at sites other than the central dunes area. Of the above common perennial grasses, the highest densities were found in A. purpurea and S. cryptandrus. Many sites contained a scattering of species of bluestem (Andropogon).

Annual grasses were also numerous; probably the most obvious annual grass was Munroa squarrosa which provided very high densities in spring

and early summer. Common witchgrass (Panicum capillare) was present in most study sites but not especially abundant anywhere. Triplasis purpurea should have become abundant in the looser, sandier areas late in the growing season but did not begin vegetative growth in any significant amount until late August.

Annual herbs were also very abundant, often showing high densities and frequencies. The most common were H. humifusa, Heliotropium convolvulaceum, Pectis angustifolia, and spurge (Euphorbia spp.). Houstonia, although very abundant in the spring and early summer, disappeared by mid or late summer. Heliotropium and Pectis appeared to pass through at least two growth cycles, a spring and early summer cycle and a second development after summer rains began. Inasmuch as the rainfall was very scattered and sporadic at the Los Medaños site during the summer, the second wave of development of these species was also sporadic.

To the southwest and west of the central dunes area, the soils become more dense and claylike, resulting in a major change in floristic composition. Toward the southeast, Larrea tridentata becomes abundant. The dominant shrubs here are L. tridentata and G. sarothrae. Quercus havardii, Artemisia filifolia and groundsel (Senecio multicapitatus) are absent from the study site. Perennial grasses showing the highest density values are Muhlenbergia torreyi, Muhlenbergia porteri, A. purpurea, and B. eriopoda. Prosopis glandulosa is present but of relatively low cover value.

The Livingston Ridge area, directly west of ERDA 9, is in many ways more interesting floristically than any other area studied. Here the ridge drops abruptly about 200 ft (61 m) to a broad valley floor ("flats"), containing large populations of tobosa grass (Hilaria mutica). This plant is generally very uncommon in other parts of the Los Medaños site. To obtain the greatest advantage from sampling of Livingston Ridge, transects were run across the ridge proper, down the precipice, and across the tobosa flats. The shrubby dominants at the top of the ridge included mescat acacia (Acacia constricta), Q. havardii, G. sarothrae, and Y.

campestris. Common perennial herbs were croton (Croton dioicus) and lanceleaf ratany (Krameria lanceolata). Muhlenbergia porteri is the most abundant perennial grass here.

The Acacia-dominated association on the ridge changes to a Larrea-Krameria association on the flats below the ridge with frequent admixtures of cacti such as Opuntia phaeacantha and Klein cholla (Opuntia kleiniae). Two perennial grasses showed high density values. These grasses are A. purpurea and H. mutica. Gutierrezia was relatively unimportant here and Acacia was absent. Certain areas of the low flats supported sparse stands of Y. torreyi, a species found also on the east mesa. Note location of study plots on Figure 3.1.

Biomass Studies

Our goal in this part of the project was that of obtaining some preliminary data for both reproductive and aboveground vegetative biomass for selected taxa. The selected taxa included desert bluets (H. humifusa), creosotebush (L. tridentata), shinnery oak (Q. havardii), and mesquite (P. glandulosa). Houstonia and Quercus were harvested from 1 x 10-m plots, Larrea from a 10-m x 10-m plot. Density, average canopy cover, and plant height were determined for Quercus and Larrea. Because of the large size of these shrubs, Prosopis was sampled by selecting three plants of different sizes (height and canopy cover). Plants were harvested to ground level and oven-dried. Values received can be converted to biomass per hectare.

Reproductive biomass studies involved two phases: flowering and fruiting biomass in the species listed above. Flowering biomass was determined for Larrea and Prosopis. In Larrea, the flowers were picked by hand from all shrubs in a 10 x 10-m study area as new phases of flowering occurred. In Prosopis, the flowers from five shrubs of assorted sizes in the "mesquite study site" were also hand-picked as new phases of flowering occurred. Flowers were initially sampled on May 17, 1978 and followed up in July 1978. All flowers and inflorescences were removed at that time,

including buds and older flowers. Quercus produced few flowers and practically no mature fruit during 1978, and flowering biomass was not taken for Houstonia. An analysis of these collections from fresh weights is presented in Table 3.5. A synopsis of dry weight values for floral biomass is presented in Table 3.6.

Fruiting biomass was sampled when fruit or seeds were mature from Houstonia, Larrea, and Prosopis. Mature fruits were taken from Houstonia plants in a 1 x 10-m plot. Fruits from Larrea were sampled from a 10 x 10-m plot. Fruits from Prosopis were sampled from five selected plants. Fruits were oven-dried; seeds and pericarp were separated and weighed.

Discussion and Conclusions

The 1978 floristic analysis of the Los Medaños study site indicates that the area can be divided into six major floristic communities and several less important associations. These divisions are roughly analogous to the biological regions in the entire WIPP study area (Chapter 1). The more important floristic communities are located on the upper mesa to the east with the highest taxon density represented by Scleropogon brevifolius, G. sarothrae, M. torreyi, Tridens pulchellus, and B. eriopoda. On the basis of cover, this area would be classified as a Prosopis-Gutierrezia-Scleropogon-Bouteloua association. Opuntia phaeacantha is relatively common in this area but does not contribute in a major way to either density or cover. Both shrub and herb vegetation have been subjected to considerable overgrazing and browzing, thus the range is in relatively poor condition. Other prominent features of the east mesa flora include a scattering of Y. torreyi, jointfir (Ephedra torreyana), and Perezia nana. In a wet year the mesa would probably be represented by two or three times more cover.

To the south, and at a slightly lower elevation, the mesa vegetation merges gradually with an association dominated by Q. havardii, G. sarothrae, and Y. campestris. Y. campestris is completely absent in the higher mesa area. Q. havardii is absent in the mesa vegetation, this

taxon remains relatively constant in both density and cover throughout the somewhat lower elevational slopes to the south for a distance of about five miles. A Prosopis profile from north to south would show a large increase in density to the south of the mesa with an inverse relationship to cover.

To the west of the mesa area, there is a steep incline down to the stable central dune area. This comprises various sandy soil types occupying the central, north central, and extreme northwestern part of the Los Medaños site. The dominant shrubs in this approximately 60-square-mile section are primarily P. glandulosa, Q. havardii, and A. filifolia, but the three species differ considerably from study site to study site. G. sarothrae is also an important shrubbery component of many of the study sites of the central dunes area, but is essentially absent in several sites. A number of grasses add considerably to the cover in this area, most of these perennials, comprising both warm weather and cool weather species. During the summer, species of Aristida and Sporobolus rank highest in both density and cover--Aristida represented by densities ranging, for the most part, from 7,000 to 29,000 per ha, and Sporobolus spp. with densities ranging from about 6,000 to 29,000 per ha.

Later in the growing season a cool weather annual, T. purpurea, becomes prominent on the loose sand areas, mostly from late August throughout the fall months. Triplasis in mature condition was not yet in sufficient evidence by the end of the 1978 sampling period to be an important part of our current analysis. From spring to midsummer an annual, M. squarrosa, is practically ubiquitous in the dunes area, often exhibiting very high densities. Other grasses variable in density in this area include Paspalum setaceum and Leptoloma cognata. Three annual forbs are also nearly ubiquitous in the dunes area: H. convolvulaceum, P. angustifolia, and H. humifusa. All of these tend to phase out of the sampling picture by midsummer but return to prominence through germination of seeds from the spring population after summer rains begin.

The only Yucca in the dunes is Y. campestris, occurring in all sites studied with density values ranging from 100 to 1500 per ha. Flower production in Y. campestris was very sparse in 1978, with approximately one plant in 2,000 producing a flowering scape.

In the extreme northern and southern parts of the stabilized dune area, there are significant areas of active dunes, exhibiting a different floristic composition from that of the stabilized dunes. A small tree, Sapindus drummondii, occurs in considerable numbers here but also occurs in small populations at scattered sites elsewhere. A very common midsummer annual in these deep loose sands is the monotypic Reverchonia arenaria.

Because of the imminence of potential disturbance in the ERDA 9 area, studies in this area were somewhat more detailed than in the extended area. Eight 1-ha study plots were established throughout the area to give good distribution for analysis. The dominant shrubs are P. glandulosa with densities of 9 to 220 per ha, Q. havardii with densities of 7,000 to 47,000 per ha, and A. filifolia with densities of 1,000 to 5,000 per ha. Gutierrezia sarothrae, often a codominant in other areas, occurs only sporadically here. The dominant perennial grasses are A. purpurea, A. longiseta, A. barbata, Cenchrus incertus, S. cryptandrus, S. giganteus, and P. setaceum. The annual grass showing the highest density value is M. squarrosa. Important perennial herbs include Croton dioicus and Eriogonum Leptocladon. In general, the floristic composition of the ERDA 9 area is similar throughout.

To the southwest and west of the ERDA 9 site, in the clay flats, L. tridentata becomes dominant. Although Flourensia cernua is not common enough to be a codominant with Larrea, it is found in varying densities throughout the Larrea flats area. This section is primarily a Larrea-Gutierrezia-Prosopis association. Gutierrezia sarothrae densities range to as high as 5,500 per ha. The ecotone bordering the sandier areas contains a scattering of Y. campestris. Common perennial grasses here include B. eriopoda, M. porteri, and M. torreyi. There was no great

variety of perennial herbs but C. dioicus and hogpotato (Hoffmanseggia jamesii) have densities of 1,000 to 3,000 per ha.

The western boundary of the study site runs along the north-south oriented Livingston Ridge; this area is markedly different floristically from all the rest of the site. The approaches to the edge of the precipice, which marks the line between the ridge and the tobosa flats at the lower level, are characterized by the dominants Acacia constricta, Q. havardii, Y. campestris, and Gutierrezia spp. Relatively high densities of Opuntia kleiniae, Greggia camporum, and Krameria lanceolata are also in evidence. Common grasses are A. purpurea, C. incertus, and Sporobolus spp.

Below the ridge in the so-called tobosa flats, another association occurs. Here the shrub dominants are L. tridentata and G. sarothrae. Also relatively common are Krameria spp., O. phaeacantha, and O. kleiniae. The most abundant grasses, as reflected in relative density values, are Aristida spp., Hilaria mutica, and M. torreyi.

Although a considerable amount of work was carried out in the Livingston Ridge area during mid- and late summer, a great deal of study remains to be done in this area.

Plans for an extension of studies at the Los Medaños site include the establishment of additional 1-ha plots in the spring of 1979 to give a more accurate picture of localized vegetational differences and more sophisticated studies of biomass and phenology. A list of taxa is presented in Table 3.7.

The vegetation of the Los Medaños site includes a number of floristic associations with affinities of the Chihuahuan desert and southern Great Plains (Fig. 3.24). The density and cover values vary considerably from study site to study site and seem to reflect differences in soil types. The flora in the Los Medaños study site is highly variable, both in relation to dominant shrubs and to grasses and herbaceous forbs. Two hundred twenty taxa have been studied to date, but many more are presently being processed for vouchering.

Acknowledgments

We express our appreciation for the cooperation extended by Dr. Pat Brannen, Mr. Douglas Jackson, and the other principal investigators, and especially for the advice, counsel, and help of Dr. Troy Best whose assistance was vital in obtaining use of computer facilities at Eastern New Mexico University and Sandia Laboratories.

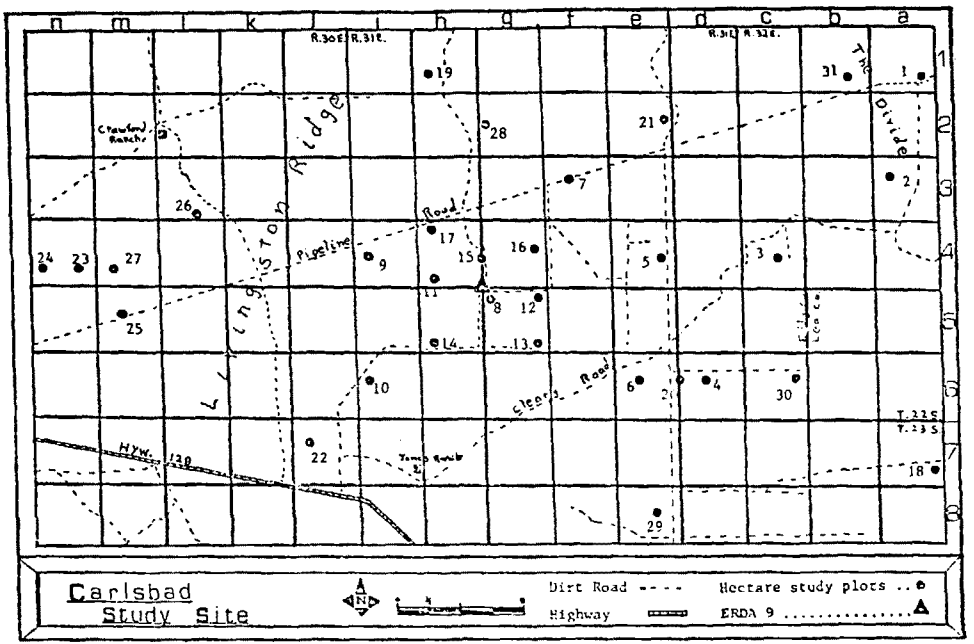


Figure 3.1. Map of Study Area Showing Numbered Study Sites and Other Features. Area surrounding ERDA 9 is represented by coordinates h 4,5 and g 4,5.

Topographic Map of Vegetation Coverage

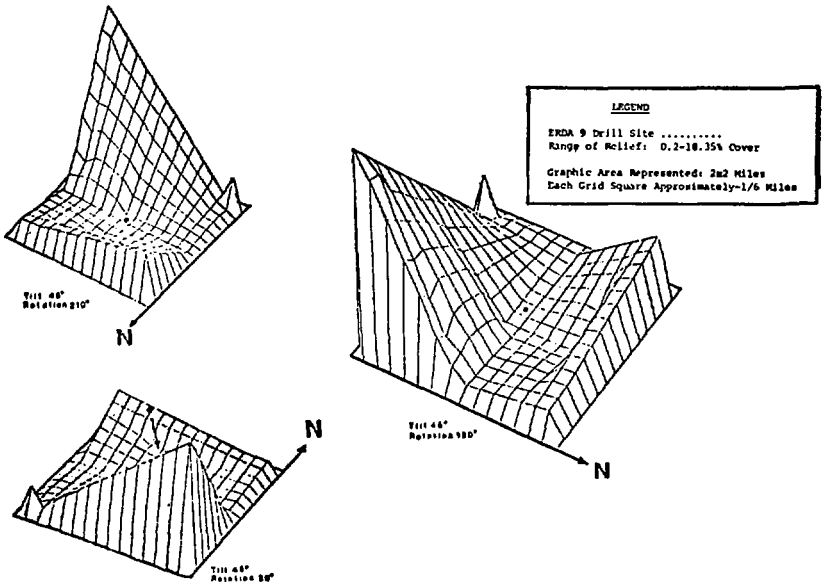


Figure 3.2. Computer-Generated 3-Dimensional Map of Relative Coverage, *Prosopis glandulosa*, Mesquite, ERDA 9 Area.

Topographic Map of Vegetation Coverage

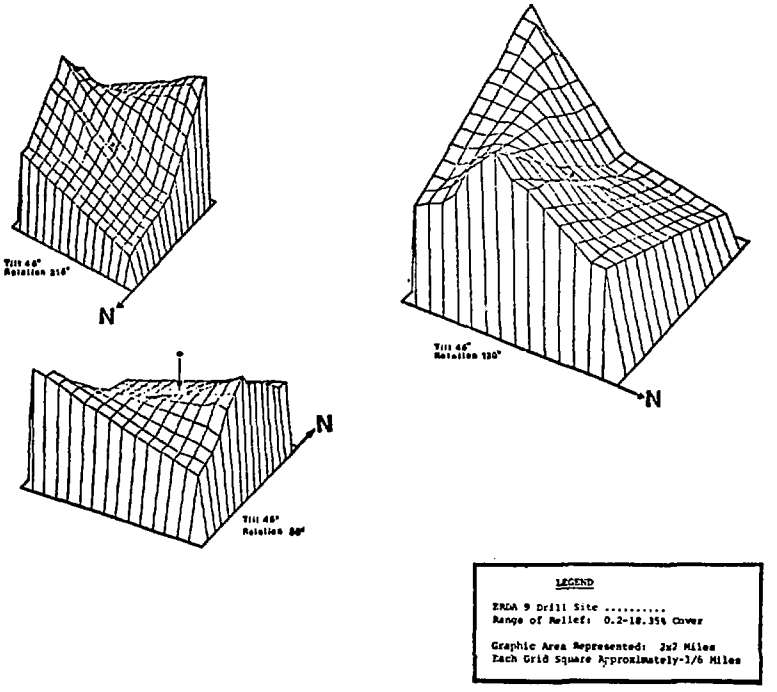


Figure 3.3. Computer-Generated 3-Dimensional Map of Relative Coverage, *Quercus havardii*, Havard (Shinnery) Oak, ERDA 9 Area.

Topographic Map of Vegetation Coverage

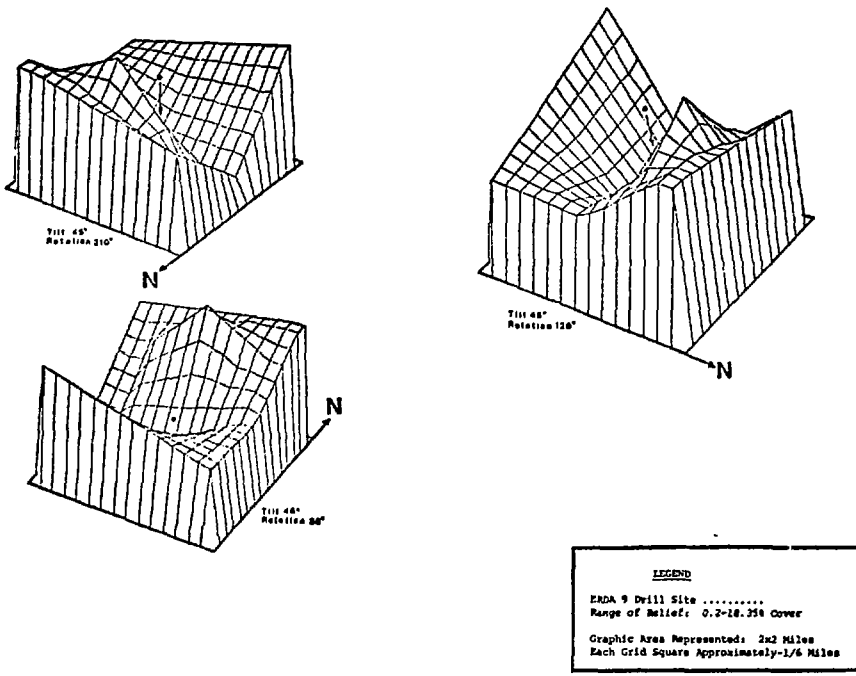


Figure 3.4. Computer-Generated 3-Dimensional Map of Relative Coverage, *Artemisia filifolia*, Sand Sagebrush, ERDA 9 Area.

Topographic Map of Vegetation Coverage

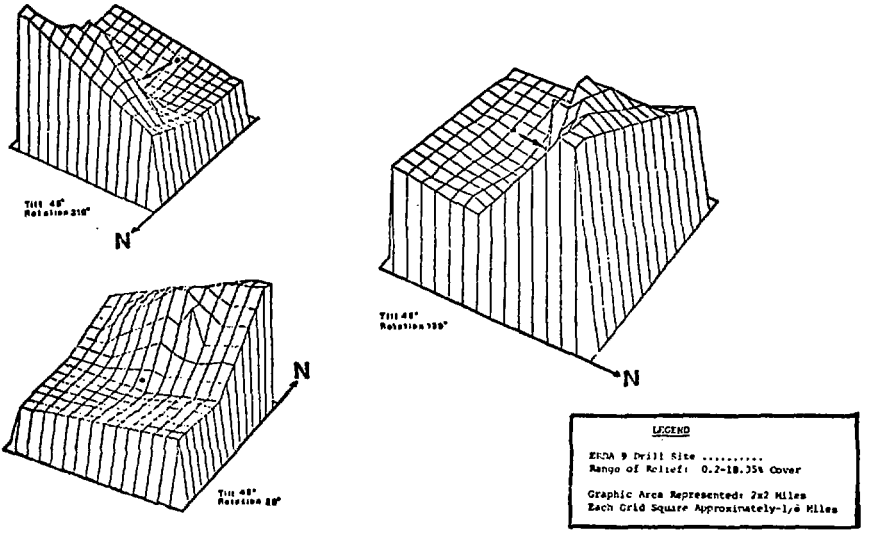


Figure 3.5. Computer-Generated 3-Dimensional Map of Relative Coverage, Sporobolus spp., Dropseed, ERDA 9 Area.

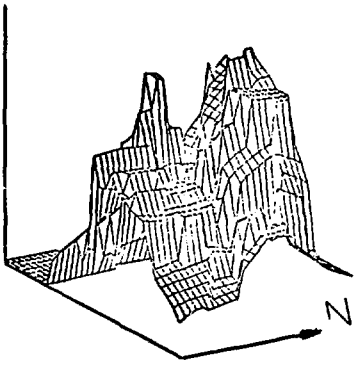


Figure 3.6. Quercus havardii, Shinnery Oak

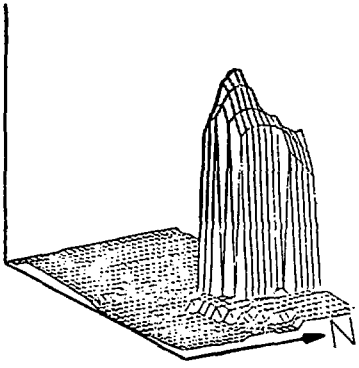


Figure 3.7. Prosopis glandulosa, Honey Mesquite

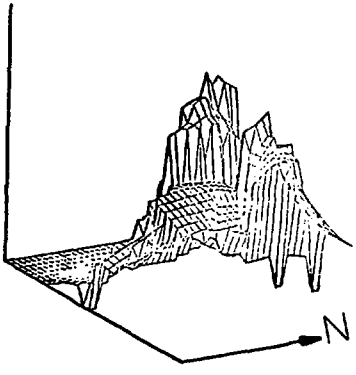


Figure 3.8. Artemisia filifolia, Sand Sagebrush

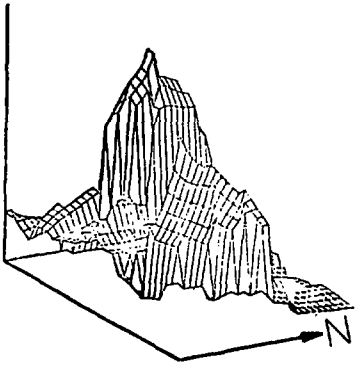


Figure 3.9. Yucca campestris, Dune Yucca

Figures 3.6-3.9. Computer-Generated Maps of Relative Cover, Entire Study Site.

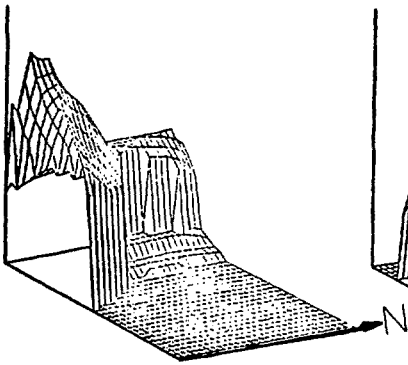


Figure 3.10. Larrea tridentata, Creosote Bush

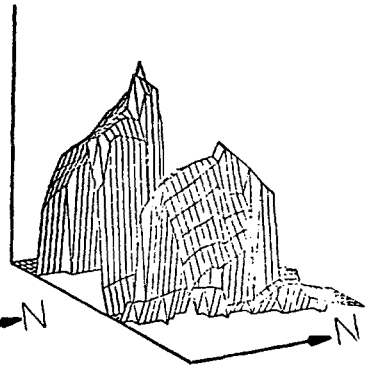


Figure 3.11. Senecio multicapitatus, Groundsel

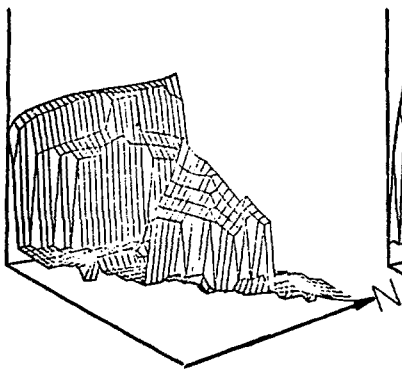


Figure 3.12. Aristida spp., Three-Awn

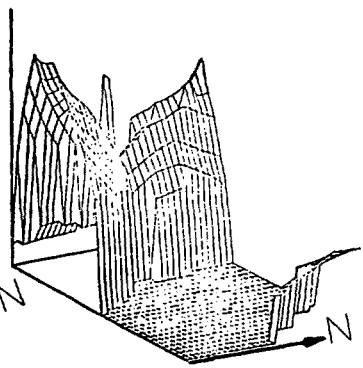


Figure 3.13. Muhlenbergia spp., Muhly

Figures 3.10-3.13. Computer-Generated Maps of Relative Cover, Entire Study Site

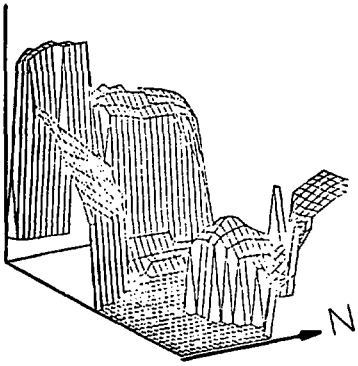


Figure 3.14. Gutierrezia spp., Snakeweed

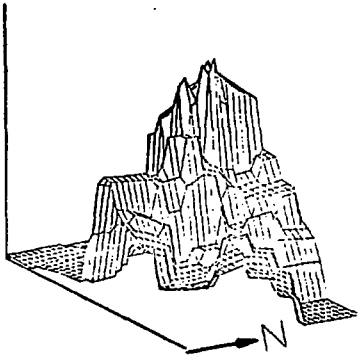


Figure 3.15. Sporobolus spp., Dropseed

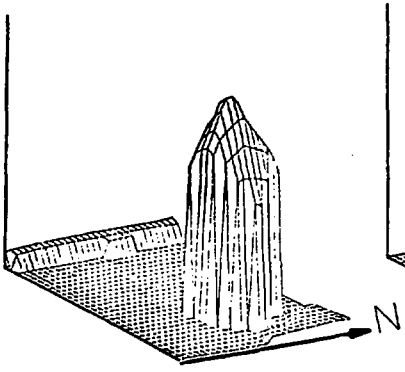


Figure 3.16. Opuntia spp., Cholla

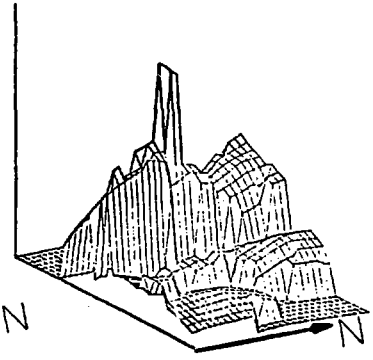


Figure 3.17. Houstonia humifusa, Desert Bluets

Figures 3.14-3.17. Computer-Generated Maps of Relative Cover, Entire Study Site.

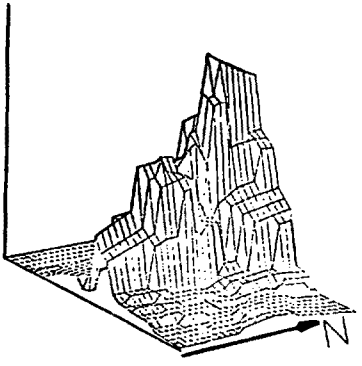


Figure 3.18. Munroa squarrosa, False Buffalograss

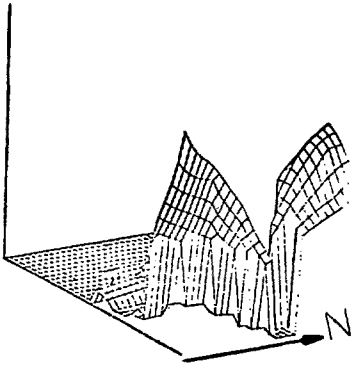


Figure 3.19. Croton dioicus, Rosval

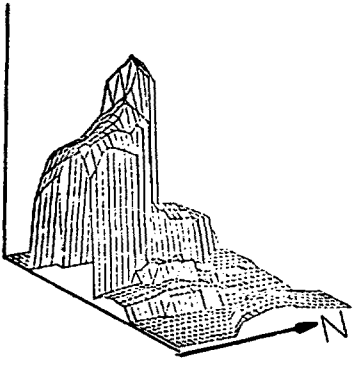


Figure 3.20. Euphorbia spp., Spurge

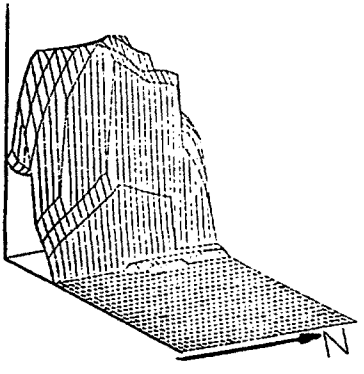


Figure 3.21. Acacia constricta, Mescat acacia

Figures 3.18-3.21. Computer-Generated Maps of Relative Cover, Entire Study Site.

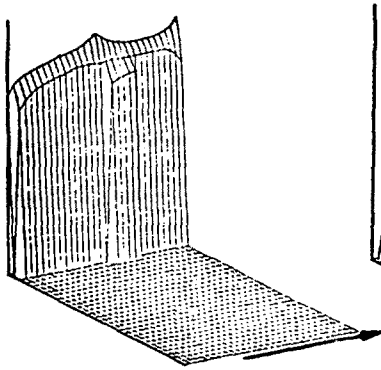


Figure 3.22. Hilaria mutica, Tobosa Grass

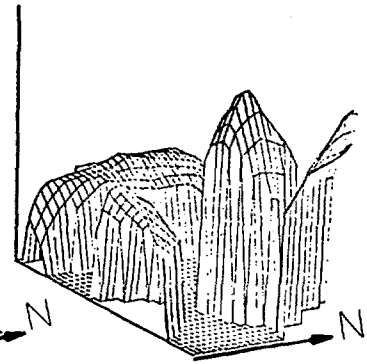
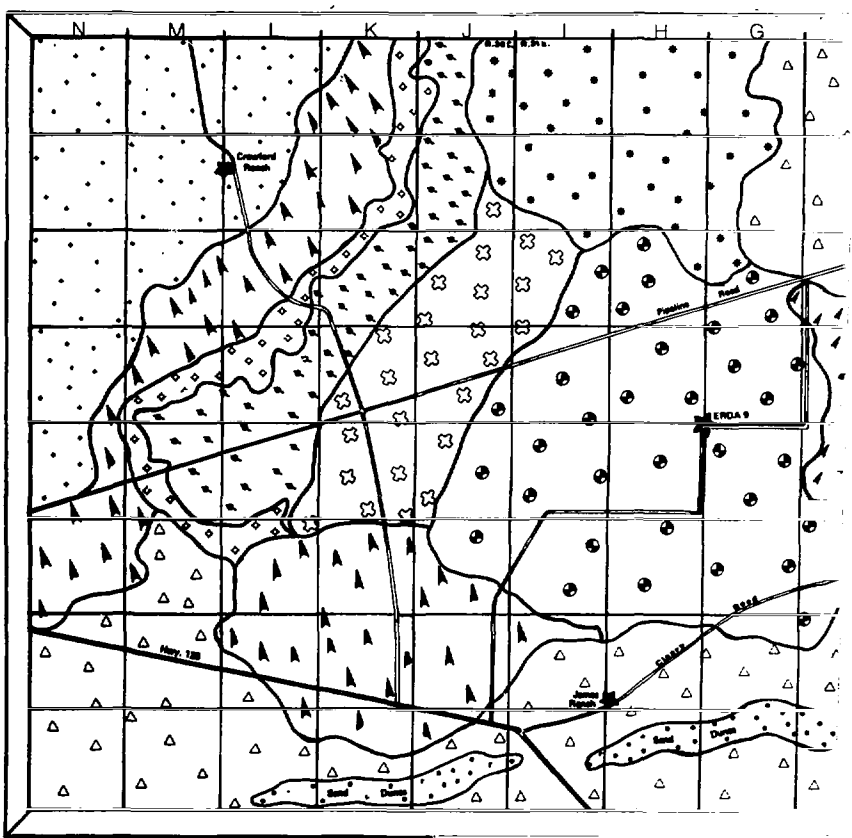


Figure 3.23. Bouteloua eriopoda, Black Grama

Figures 3.22-3.23. Computer-Generated Maps of Relative Cover, Entire Study Site



Dominants: Prosopis, Muhlenbergia, and Gutierrezia. High frequency of Tridens, Tragia, and Sphaeralcea. Occasional Yucca torreyi.

Dominants: Quercus, Aristida and Prosopis. High frequency of Muhlenbergia and Panicum.

Dominants: Quercus, Artemisia and Aristida. High frequency of Yucca, Sporobolus and Gutierrezia.

Dominants: Aristida, Gutierrezia, Prosopis and Yucca. High frequency of Artemisia and Croton.

Dominants: Prosopis, Gutierrezia, Sporobolus and Opuntia. High frequency of Artemisia and Aristida.

Dominants: Quercus, Sporobolus, Artemisia and Muhlenbergia. High frequency of Pectis and Houstonia.

Dominants: Artemisia, Prosopis, Quercus, Muhlenbergia, Sporobolus, Yucca, and Aristida. High frequency of Cenchrus, Houstonia and Panicum.

Dominants: Larrea, Gutierrezia and Muhlenbergia. High frequency of Bouteloua and Aristida.

Dominants: Prosopis, Aristida, and Quercus. Occasional Koeberlinia.

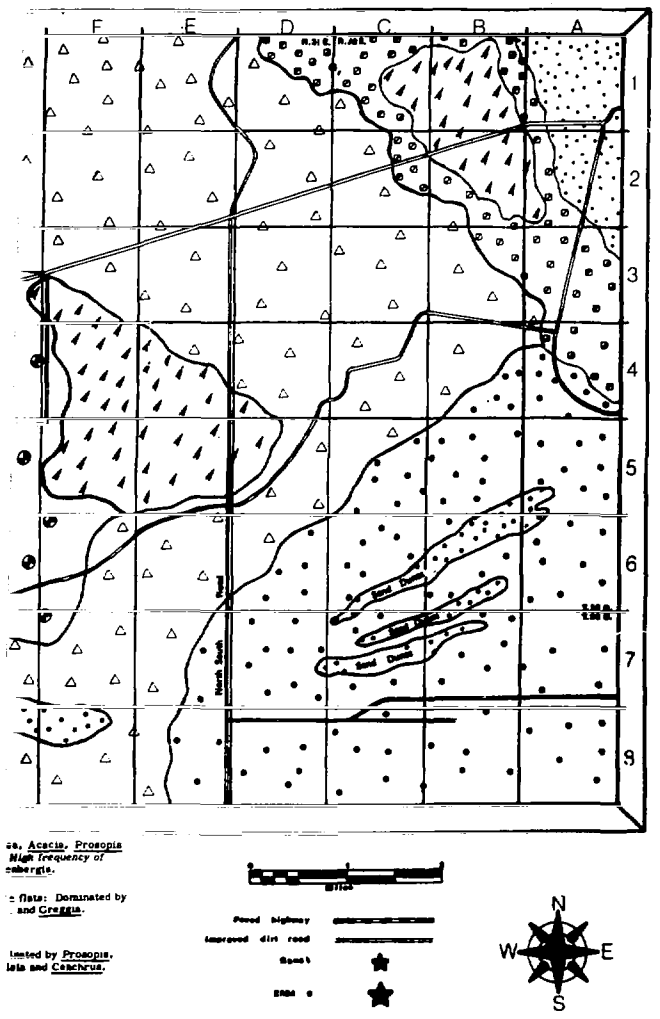
Dominants: Acacia, Quercus, Prosopis and Krameria. High frequency of Koeberlinia, Rhus, Mentzelia and Pectis.

Dominants: Larrea, Acacia, and Gutierrezia. High freque Tridens and Muhlenbergia.

Alkali soil-Tabosa flats: Dc Hilaria, Lepidium and Grea

Sand dunes: Dominated by Sapindus, Artemisia and Co

Figure 3.24. Veg



Vegetation Map - Carlsbad Study Site

Table 3.1 Comparison of Density Values in Eight 1-ha Study Plots in ERDA 9 Area. See Fig. 3.2 for location of study plots. All values X 100.

	Study Plots								
	N.C.	E.C.	S.E.	S.W.	W.C.	C.	N.W.	N.E.	Ave.
Aristida spp.	10.0	185.0	175.0	270.0	180.0	185.0	165.0	205.0	171.8
Artemisia filifolia	20.0	10.0	15.0	10.0	10.0	20.0	15.0	50.0	18.9
Bouteloua eriopoda	25.0	90.0	----	----	5.0	5.0	5.0	10.0	17.5
Croton dioicus	50.0	50.0	60.0	5.0	5.0	----	5.0	45.0	27.5
Euphorbia spp.	50.0	85.0	25.0	40.0	65.0	50.0	45.0	50.0	51.2
Gutierrezia sarothrae	----	----	----	10.0	----	----	----	----	----
Heliotropium convolvulaceum	60.0	10.0	----	40.0	10.0	----	50.0	65.0	29.4
Houstonia humifusa	330.0	825.0	50.0	3015.0	620.0	405.0	475.0	75.0	724.4
Munroa squarrosa	440.0	445.0	45.0	175.0	35.0	205.0	855.0	115.0	289.4
Muhlenbergia spp.	----	5.0	30.0	55.0	25.0	----	10.0	5.0	16.2
Pectis angustifolia	225.0	600.0	----	55.0	----	----	185.0	----	133.2
Prosopis glandulosa	.07	0.10	0.35	0.15	0.23	0.12	0.22	0.09	0.17
Quercus havardii	180.0	275.0	150.0	475.0	415.0	350.0	70.0	140.0	256.9
Senecio multicapitatus	5.0	5.0	----	10.0	10.0	5.0	5.0	5.0	5.7
Sporobolus spp.	65.0	65.0	110.0	20.0	220.0	50.0	345.0	290.0	143.6
Yucca campestris	10.0	5.0	15.0	4.0	10.0	1.0	10.0	2.0	7.12

Table 3.2 Comparison of Frequency (% of $1m^2$ quadrats) Values in Eight 1-ha Study Plots in ERDA 9 Area. See Fig. 3.2 for location of study plots.

	Study Plots								
	N.C.	E.C.	S.E.	S.W.	W.C.	C.	N.W.	N.E.	Ave.
Aristida spp.	10.0	16.0	16.0	32.0	17.0	11.0	16.0	18.5	19.5
Artemisia filifolia	6.0	6.0	10.0	11.0	5.0	5.0	12.0	12.0	8.4
Bouteloua eriopoda	3.0	3.5	—	—	—	0.5	—	1.0	1.0
Croton dioicus	5.0	5.0	6.0	—	—	—	—	4.5	2.6
Euphorbia spp.	4.0	3.0	3.0	5.0	5.0	4.0	4.0	1.0	3.6
Gutierrezia sarothrae	—	—	—	1.0	—	—	—	—	—
Heliotropium convolvulaceum	6.0	0.5	—	1.5	1.0	—	4.5	1.5	1.8
Houstonia humifusa	18.0	15.0	3.0	53.0	20.0	23.0	8.0	4.0	18.5
Munroa squarrosa	30.0	—	—	—	—	—	42.0	5.0	9.6
Muhlenbergia spp.	—	5.0	2.0	5.0	3.0	—	1.0	5.0	2.6
Pectis angustifolia	15.5	—	—	1.5	—	—	10.0	—	3.4
Prosopis glandulosa	—	—	3.0	—	1.0	—	4.0	—	1.0
Quercus havardii	26.0	32.0	23.0	50.0	40.0	46.0	12.0	45.0	34.3
Senecio multicapitatus	1.0	1.0	—	1.0	2.0	1.0	1.0	0	0.8
Sporobolus spp.	18.0	15.0	18.0	11.0	22.0	18.0	14.0	23.0	17.4
Yucca campestris	6.0	1.0	1.0	2.0	2.0	4.0	3.0	1.0	2.5

Table 3.3 Comparison of Cover (%) in Selected Taxa for Eight 1-ha Study Plots in the ERDA 9 Area. See Fig. 3.2 for location of study plots.

	Study Plots								
	N.C.	E.C.	S.E.	S.W.	W.C.	C.	N.W.	N.E.	Ave.
Aristida spp.	0.481	1.315	1.465	3.215	1.097	2.180	0.673	1.495	1.490
Artemisia filifolia	2.890	3.495	3.620	5.990	2.375	1.485	4.580	4.580	3.672
Bouteloua eriopoda	0.165	0.505	-----	-----	-----	0.080	-----	0.065	0.101
Croton dioicus	0.490	1.480	1.520	-----	-----	-----	-----	0.945	0.560
Euphorbia spp.	0.655	0.240	0.015	0.330	0.400	0.050	0.450	0.025	0.270
Gutierrezia sarothrae	-----	-----	-----	0.020	-----	-----	-----	-----	-----
Heliotropium convolvulaceum	0.420	0.015	-----	0.025	0.030	-----	0.785	0.045	0.165
Houstonia humifusa	0.620	0.065	0.085	3.045	0.545	0.425	0.360	0.360	0.800
Munroa squarrosa	2.395	-----	-----	-----	-----	-----	4.095	4.950	1.430
Muhlenbergia spp.	-----	0.235	0.100	0.135	0.120	-----	0.075	0.010	0.084
Pectis angustifolia	1.385	-----	-----	0.055	-----	-----	0.775	-----	0.276
Prosopis glandulosa	-----	-----	18.350	-----	-----	-----	-----	-----	-----
Quercus havardii	6.820	14.670	7.750	13.800	9.290	9.030	2.750	8.325	9.054
Senecio multicapitatus	0.010	0.010	-----	0.035	0.040	0.010	0.015	-----	0.015
Sporobolus spp.	2.212	1.890	2.240	1.430	2.255	1.415	1.987	2.187	1.952
Yucca campestris	2.570	0.275	0.385	0.800	1.040	1.855	1.550	1.550	1.253

Table 3.4 A List of Plants Collected at the Los Medaños Study Site During 1978

Taxa are arranged alphabetically according to family, generic name, and specific epithet. Authorities and common names are also listed. Life forms are represented by the symbols A = annual, WA = winter annual, B = biennial, P = perennial, SS = suffrutescent, S = shrubby, T = arborescent, HV = herbaceous vine, WV = woody vine. The locations of taxa in extensive or intensive areas or both (shown by the symbols E = extended, I = ERDA 9, EI = both areas) are found in parentheses following the growth form symbols.

Taxa	Common name	Growth form	
Agavaceae			
Yucca campestris McKelvey	Dune yucca	S	(EI)
Y. elata Engelm.	Palmilla	S	(E)
Y. torreyi Shafer	Torrey yucca	S	(E)
Aizoaceae			
Mollugo verticillata L	Indian chickweed	A	(I)
Amaranthaceae			
Amaranthus albus L	Tumbleweed amaranth	A	(EI)
Froelichia floridana (Nutt.) Moq. var. *campestris* (Small) Fern.	Snakecotton	A	(EI)
Guilleminea densa (Willd.) Moq. var. *aggregata* Uline & Bray	----------	P	(E)
Tidestromia lanuginosa (Nutt.) Standl.	Woolly tidestromia	A	(E)
Amaryllidaceae			
Zephyranthes longifolia Hemsl.	Zephyr-lily	P	(E)

Table 3.4 Continued

Taxa	Common name	Growth form	
Anacardiaceae			
Rhus microphylla Engelm.	Littleleaf sumac	S	(E)
Asclepiadaceae			
Asclepias arenaria Torr.	Dune milkweed	P	(I)
A. oenotherioides Cham. & Schlecht.	Primrose milkweed	P	(E)
A. viridiflora Raf.	Green-flowered milkweed	P	(E)
Bignoniaceae			
Chilopsis linearis (Cav.) Sw.	Desert willow	S	(E)
Boraginaceae			
Coldenia canescens DC.	Spreading coldenia	SS	(E)
C. hispidissima (T. & G.) Gray	Hispid coldenia	SS	(E)
Cryptantha angustifolia (Torr.) Greene	Hiddenflower	A	(E_
C. jamesii (Torr.) Payson var. laxa (Macbr.) Payson	James hiddenflower	B,P	(EI)
C. jamesii var. setosa (M. E. Jones) Shinners	----------	B,P	(E)
Heliotropium convolvulaceum (Nutt.) Gray	Bindweed heliotrope	A	(EI)
H. curassavicum L.	Salt heliotrope	P	(E)
H. greggii Torr.	Desert heliotrope	P	(E)
Lithospermum multiflorum Gray	Stoneseed	P	(EI)

Table 3.4 Continued

Taxa	Common name	Growth form	
Cactaceae			
Coryphantha macromeris (Engelm.) Lem.	Pincushion cactus	SS	(E)
Echinocactus texensis Hopff.	Texas devilshead	SS	(E)
Echinocereus caespitosus Engelm.	----------	SS	(E)
E. fendleri Engelm.	Fendler echinocereus	SS	(EI)
Opuntia kleiniae DC.	Klein cholla	SS	(E)
O. leptocaulis DC.	Christmas cactus	SS	(E)
O. phaeacantha Engelm.	Prickly pear	SS	(EI)
Caryophyllaceae			
Paronychia jamesii T. & G	Nailwort	SS	(E)
Chenopodiaceae			
Atriplex canescens (Pursh) Walt.	Four-wing saltbush	S	(E)
Chenopodium desiccatum A. Nels	Thickleaf goosefoot	A	(E)
C. hians Standl.	----------	A	(E)
C. incanum (Wats.) Heller	Goosefoot	A	(E)
Cycloloma atriplicifolia (Spreng.) Coult.	Winged pigweed	A	(EI)
Salsola kali L. var *tenuifolia* Mey.	Russian thistle	A	(EI)
Commelinaceae			
Commelina dianthifolia Delile	Birdbill dayflower	P	(E)
C. erecta L. var. *angustifolia* (Michx.) Fern.	Erect dayflower	P	(EI)

Table 3.4 Continued

Taxa	Common name	Growth form	
Tradescantia occidentalis (Britt.) Smyth	Western spiderwort	P	(E)
Compositae			
Ambrosia artemisiifolia L.	Short ragweed	A	(E)
Aphanostephus ramosissimus DC.	----------	A	(E)
Artemisia filifolia Torr.	Sand sagebrush	SS	(EI)
A. ludoviciana Nutt.	Wormwort	P	(E)
Baccharis wrightii Gray	Wright baccharis	SS	(E)
Bahia pedata Gray	Bahia	A	(E)
Baileya multiradiata Harv. & Gray	Desert marigold	A,P?	(E)
Chrysothamnus pulchellus (Gray) Greene	Southwest rabbitbrush	S	(E)
C. spathulatus L. C. Anderson	----------	S	(E)
Cirsium spp. (rosette)	Thistle	P	(E)
Conyza coulteri Gray	----------	A	(E)
Dyssodia pentachaeta (DC.) Robins. var. hartwegii (Gray) Strother	Dogweed	P	(E)
Erigeron bellidiastrum Nutt.	Western fleabane	A	(E)
Flourensia cernua DC.	Tarbush	S	(E)
Franseria confertiflora (DC.) Rydb.	Bursage	A	(E)
Gaillardia pinnatifida Torr	Pinwheel	P	(E)
G. pulchella Fouq.	Firewheel	A	(E)

Table 3.4 Continued

Taxa	Common name	Growth form	
Gutierrezia microcephala (DC.) Gray	Smallhead snakeweed	SS	(E)
G. sarothrae (Pursh) Britt. & Rusby	Snakeweed	SS	(EI)
Haplopappus spinulosus (Pursh) DC. var. australis (Greene) Hall	Spiny yellow aster	P	(E)
H. spinulosus var. glaberrimus (Rydb.) Blake	----------	P	(E)
H. spinulosus var. scabrellus (Greene) Hall	----------	P	(E)
Helianthus petiolaris Nutt.	Prairie sunflower	A	(EI)
Heterotheca psammophila Wagenkn.	----------	A	(EI)
Hymenopappus flavescens Gray var. cano-tomentosus Gray	White ragweed	A,B	(E)
Hymenoxys scaposa (DC.) Parker var. glabra (Nutt.) Parker	Smooth hymenoxys	P	(E)
H. scaposa var. scaposa	----------	P	(E)
Leucelene ericoides (Torr.) Greene	Baby white aster	P	(E)
Machaeranthera tanacetifolia (H.B.K.) Nees	Aster	A	(E)
Melampodium cinereum DC.	Blackfoot	P	(E)
M. leucanthum T. & G.	Blackfoot	P	(EI)

Table 3.4 Continued

Taxa	Common name	Growth form	
Palafoxia sphacelata (Torr.) Cory	----------	A	(EI)
Parthenium confertum Gray	Desert feverfew	P,B	(E)
Pectis angustifolia Torr.	Fetid marigold	A	(EI)
Perezia nana Gray	Dwarf holly	P	(E)
P. wrightii Gray	Wright desert holly	P	(E)
Psilostrophe tagetina	Paper daisy	P	(E)
P. villosa Rydb.	Desert paperflower	B	(E)
Ratibida tagetes (James) Barnh.	Prairie coneflower	P	(E)
Sartwellia flaveriae Gray	Gypsumweed	A	(E)
Senecio multicapitatus Greenm.	Groundsel	P	(EI)
Stephanomeria pauciflora (Torr.) A. Nels.	Wire lettuce	P	(E)
Thelesperma megapotamicum (Spreng.) O. Ktze.	Greenthread	P	(E)
Verbesina encelioides (Cav.) Gray	Golden crownbeard	A	(E)
Xanthocephalum texanum (DC.) Shinners	Snakeweed	SS	(E)
Zinnia grandiflora Nutt.	Zinnia	P	(EI)
Convolvulaceae			
Cuscuta leptantha Engelm.	Dodder	A	(E)
Evolvulus nuttallianus R. & S.	----------	P	(E)

Table 3.4 Continued

Taxa	Common name	Growth form	
Cruciferae			
Descurainia pinnata (Walt.) Britt. var. *halictorum* (Cockll.) Detling	Tansy mustard	A	(E)
Dithyrea wislizenii Engelm.	Spectacle pod	A	(E)
Erysimum asperum (Nutt.) DC.	Western wallflower	P,A	(E)
Greggia camporum Gray var. *linearifolium* (Wats.) M.E. Jones	----------	P	(E)
Lepidium virginicum L var. *medium* (Greene) C.L. Hitchc.	Peppergrass	A,B	(EI)
Lesquerella fendleri (Gray) Wats.	Bladder pod	P	(E)
Cucurbitaceae			
Cucurbita digitata Gray	----------	P	(E)
Cucurbita foetidissima H.B.K.	Buffalogourd	P	(E)
Ibervillea tenuisecta (Gray) Small	----------	P	(E)
Ibervillea tripartita (Naud.) Greene	----------	P	(E)
Cyperaceae			
Cyperus schweinitzii Torr.	Flat sedge	P	(EI)

Table 3.4 Continued

Taxa	Common name	Growth form	
Euphorbiaceae			
Croton dioicus Cav.	Croton	P	(EI)
Croton glandulosa L. var. *lindheimeri* Muell. Arg.	Croton	A	(E)
Croton texensis (Klotzch) Muell. Arg.	Texas croton	A	(EI)
Ditaxis neomexicana (Muell. Arg.) Heller	----------	P	(E)
Euphorbia fendleri T. & G.	Spurge	P	(E)
Euphorbia glyptosperma Engelm.	Ridge seed spurge	A	(E)
Euphorbia lata Engelm.	Spurge	P	(E)
Euphorbia missurica Raf.	Spurge	A	(EI)
Euphorbia serpens H.B.K.	Serpent spurge	A	(EI)
Euphorbia serpyllifolia Pers.	Thymeleaf spurge	A	(E)
Euphorbia serrula Engelm.	Spurge	A	(E)
Phyllanthus abnormis Baill. var. *abnormis*	----------	A	(E)
Reverchonia arenaria Gray	----------	A	(E)
Tragia stylaris Muell. Arg.	Noseburn	P	(E)
Ephedraceae			
Ephedra torreyana Wats.	Joint fir	S	(E)

Table 3.4 Continued

Taxa	Common name	Growth form	
Fagaceae			
Quercus havardii Rydb.	Havard oak	S	(EI)
Gentianaceae			
Centaurium calycosum (Buckl.) Fern. var. *breviflorum* Shinners	----------	P	(E)
Gramineae			
Andropogon barbinodis (Lag.) Hester	Cane bluestem	P	(E)
Aristida barbata Fourn.	Havard three-awn	P	(EI)
Aristida longiseta Steud.	Red three-awn	P	(EI)
Aristida purpurea Nutt.	Purple three-awn	P	(EI)
Aristida wrightii Nash	Three-awn	P	(E)
Bouteloua barbata Lag.	Sixweeks grama	A	(E)
Bouteloua curtipendula (Michx.) Torr.	Side-oats grama	P	(E)
Bouteloua eriopoda (Torr.) Torr.	Black grama	P	(E)
Bouteloua hirsuta Lag.	Hairy grama	P	(EI)
Brachiaria ciliatissima (Buckl.) Chase	----------	P	(EI)
Cenchrus incertus M.A. Curtis	----------	P	(EI)
Chloris cucullata Bisch	----------	P	(E)
Eragrostis arida Hitchc.	----------	A	(EI)
Eragrostis secundiflora Presl	----------	P	(EI)

Table 3.4 Continued

Taxa	Common name	Growth form	
Hilaria mutica (Buckl.) Benth.	Tobosa	P	(E)
Leptoloma cognata (Schult.)	Fall witchgrass	P	(EI)
Muhlenbergia porteri Scribn.	Bush muhly	P	(EI)
M. torreyi (Kunth.) Hitchc.	Ring muhly	P	(E)
Munroa squarrosa (Nutt.) Torr.	False buffalograss	A	(EI)
Panicum capillare L.	Common witchgrass	A	(EI)
P. obtusum H.B.K.	Vine-mesquite	P	(E)
Paspalum setaceum Michx.	Paspalum	P	(EI)
Scleropogon brevifolius Phil.	Burrograss	P	(EI)
Setaria leucophila (Scribn. & Merr.) K. Schum.	Bristlegrass	P.	(E)
S. macrostachya H.B.K.	Plains bristlegrass	P.	(EI)
Sporobolus cryptandrus (Torr.)	Sand dropseed	P.	(EI)
S. giganteus Nash	Giant dropseed	P.	(EI)
Trichachne californica (Benth.) Chase	Arizona cottontop	P	(E)
Tridens pulchellus (H.B.K.) Hitchc.	Fluffgrass	P	(E)
Triplasis purpurea (Walt.) Chapm.	Purple sandgrass	A	(E)
Hydrophyllaceae			
Phacelia corrugata A. Nels.	Scorpionweed	A	(E)
P. integrifolia Torr.	----------	A,B	(E)
Koeberliniaceae			
Koeberlinia spinosa Zucc.	Allthorn	S	(E)

Table 3.4 Continued

Taxa	Common name	Growth form	
Labiatae			
Monarda punctata L. var. *lasiodonta* Gray	Spotted horsemint	A	(E)
Scutellaria drummondii	Drummond skullcap	A	(E)
Leguminosae			
Acacia constricta Gray	Mescat acacia	S	(E)
Cassia bauhinioides Gray	Senna	P	(E)
Dalea formosa Torr.	Featherbush	S	(E)
D. lanata Spreng.	Woolly dalea	P	(EI)
Hoffmanseggia jamesii T. & G.	Hogpotato	P	(EI)
Krameria lanceolata Torr.	Lanceleaf ratany	P	(E)
K. glandulosa Rose & Painter	Ratany	S	(E)
Prosopis glandulosa Torr.	Mesquite	S	(EI)
Linaceae			
Linum aristatum Engelm.	Plains flax	P	(EI)
L. aristatum var. *australe* (Heller) K. & P.	----------	P	(EI)
Loasaceae			
Cevallia sinuata Lag.	----------	P	(E)
Mentzelia humilis (Urb. &. Gilg.) Darl.	Stickleaf	P	(E)
M. reverchonii (Urb. & Gilg) Thomps. & Zavortink	Reverchon stickleaf	P	(E)
M. strictissima (W. & S.) Darl.	Prairie stickleaf	P	(EI)

Table 3.4 Continued

Taxa	Common name	Growth form	
Malvaceae			
Sida physocalyx Gray	----------	P	(E)
Sphaeralcea coccinea (Pursh) Rydb.	Rosemallow	P	(E)
S. digitata (Greene) Rydb.	Digitate rosemallow	P	(E)
S. subhastata Coult.	Coulter rosemallow	P	(E)
Martyniaceae			
Proboscidea sabulosa Correll	Dune unicornplant	A	(E)
Nyctaginaceae			
Abronia fragrans Nutt.	Snowball sandverbena	A	(E)
Acleisanthes longiflora Gray	Angel trumpets	P	(E)
Ammocodon chenopodioides (Gray) Standl.	Goosefoot moonpod	P	(E)
Boerhaavia intermedia M. E. Jones	Spiderling	A	(I)
Oxybaphus linearis (Pursh) Robins. var. *decipiens* (Standl.) K. & P.	Narrow-leaved 4-o'clock	P	(EI)
Selinocarpus diffusus Gray	Spreading moonpod	P	(E)
Oleaceae			
Menodora scabra Gray var. *ramosissima* Steyerm.	Rough menodora	SS	(E)
Onagraceae			
Calylophus hartwegii (Benth.) Raven subsp. *pubescens* (Gray) Towner & Raven		P	(E)

Table 3.4 Continued

Taxa	Common name	Growth form	
Calylophus serrulatus (Nutt.) Raven	----------	P	(EI)
Gaura villosa Torr.	Hairy gaura	SS	(I)
Oenothera albicaulis Pursh	Evening primrose	A	(I)
O. biennis L. subsp. *centralis* Munz	Dune primrose	P	(E)
O. neomexicana (Small) Munz	New Mexico evening primrose	A	(E)
Orobanchaceae			
Orobanche multiflora Nutt.	Broomrape	A	(E)
Polemoniaceae			
Ipomopsis longiflora (Torr.) V. Grant	Blue gilia	A	(E)
I. pumila (Nutt.) V. Grant	----------	A	(E)
Polygonaceae			
Eriogonum polycladon Benth.	Woolly buckwheat	A	(EI)
E. rotundifolium Benth.	Roundleaf buckwheat	A	(E)
Polypodiaceae			
Notholaena sinuata (Lag.) Kaulf var. *chochisensis* (Gooding) Weatherby	Cloakfern	P	(E)
Portulacaceae			
Portulaca parvula Gray	Small purslane	A	(I)
P. retusa Engelm.	----------	A	(E)
Talinum angustissimum (Gray) Woot. & Standl.	Fameflower	P	(E)

Table 3.4 Continued

Taxa	Common name	Growth form	
Rhamnaceae			
Microrhamnus ericoides Gray	Javelinabush	S	(E)
Ziziphus obtusifolia (T. & G) Gray	Lotebush	S	(E)
Rubiaceae			
Houstonia humifusa Gray	Bluets	A	(EI)
Rutaceae			
Thamnosma texana (Gray) Torr.	Dutchman's breeches	P	(E)
Sapindaceae			
Sapindus drummondii H. & A.	Drummond soapberry	T	(EI)
Scrophulariaceae			
Castilleja sessiliflora Pursh.	Desert paintbrush	P	(E)
Linaria texana Scheele	Texas toadflax	A	(E)
Maurandya wislizenii Engelm.	Vining snapdragon	HV,P	(EI)
Penstemon ambiguus Torr.	Plains beardtongue	SS	(EI)
P. fendleri T. & G.	Fendler beardtongue	P	(E)
Solanaceae			
Chamaesaracha conioides (Moric.) Britt.	----------	P	(E)
Lycium berlandiera Dun.	Wolfberry	S	(E)
Nicotiana trigonophylla Dun.	Wild tobacco	B,P	(E)
Physalis lobata Torr.	Ground cherry	A	(E)
P. hederaefolia Gray var. *cordifolia* (Gray) Waterfall	Clammy groundcherry	P	(E)
Solanum elaeagnifolium Cav.	Horsenettle	P	(EI)

Table 3.4 Continued

Taxa	Common name	Growth form	
Solanum rostratum Dun.	Spiny nightshade	A	(E)
Ulmaceae			
Celtis reticulata Torr.	Netleaf hackberry	T	(E)
Umbelliferae			
Eurytaenia texana T. & G.	----------	A	(E)
Verbenaceae			
Aloysia wrightii (Gray) Heller	Wright lemonverbena.	S	(E)
Tetraclea coulteri Gray	----------	P	(E)
Verbena bracteata Lag. & Rodr.	Prostrate verbena	A	(E)
V. ciliata Benth.	----------	A	(E)
V. plicata Greene	Fanleaf verbena	A	(E)
V. wrightii Gray	Desert verbena	A	(E)
Violaceae			
Hybanthus verticillatus (Ort.) Baill.	Green violet	P	(E)
Zygophyllaceae			
Kallstroemia grandiflora Gray	Desert poppy	A	(E)
Larrea tridentata (DC.) Cov.	Creosotebush	S	(E)
Tribulus terrestris L.	Goathead	A	(EI)

Table 3.5 An Analysis of Floral Biomass from 5 Plants in Mesquite Sampling Plot

Sampling Categories	Weight (gms) in samples					Numbers of flowers in samples				
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 1	No. 2	No. 3	No. 4	No. 5
Total biomass - fresh weight	1636.00	56.00	300.00	1105.00	150.00					
Total no. flowers - 30 catkin sample						3959	3385	3824	3625	2166
Flower weight per sample	9.33	7.69	9.068	7.50	4.76					
Axis weight per sample	1.70	1.62	1.45	1.88	1.00					
Average weight of each flower	0.0023	0.00227	0.0023	0.0020	0.0021					
Average weight of each axis	0.0586	0.054	0.048	0.062	0.0333					
Estimate total flowers during flowering period (actual flowers plus empty pedicels)										
Total biomass per 30 catkin sample	11.03	9.61	10.51	9.38	5.76	4717	3961	4171	4191	2585
Hypothetical biomass projected through flowering period	12.609	10.611	11.043	10.262	6.428					
Total sample values										
Approximate axis weight	251.000	9.44	92.4	221.00	23.25					
Approximate flower weight	1385.00	46.56	295.6	884.00	126.75					
Approximate flower number						602,173	20,511	128,521	442,000	69,800

Table 3.6 Compilation of Dry Weight Values for Flower Biomass Studies, Mesquite Plot

Plant number	Oven-dry weight (gms)	
1	344.41	
2	16.08	
3	89.08	
4	309.41	
5	45.12	
	Total floral dry weight	804.10
	Average floral dry weight per plant	160.82

Table 3.7 A List of Taxa and Observed Phenological Data from Los Medanos, 2/2/78–9/30/78

Taxa	Dates of 1st growth	1st flowers	Max. flowers	Fruit mat.	Dormancy
Agavaceae					
Yucca campestris	4/7	5/15	5/15	6/26	9/24+
Y. elata	—	—	—	7/31	9/24+
Y. torreyi	4/20	5/15	6/15	7/10	9/10+
Aizoaceae					
Mollugo verticillata	5/15	6/26	8/14	9/8	9/24+
Amaranthaceae					
Amaranthus albus	5/15	—	6/26	8/15	9/24+
Froelichia floridana campestris	—	7/17	9/8	9/8	9/24+
Guilleminea dense aggregata	—	5/15	—	—	—
Tidestromia lanuginosa	6/12	7/31	9/9	—	9/24+
Amaryllidaceae					
Zephyranthes longifolia	—	—	—	—	—
Anacardiaceae					
Rhus microphylla	—	4/7	—	5/15	—
Asclepiadaceae					
Asclepias arenaria	4/7	6/13	—	—	—
A. asnotherioides	5/15	—	6/26	8/1	—
A. viridiflora	4/7	6/26	6/26	8/17	—
Bignoniaceae					
Chilopsis linearis	—	6/1	6/15	8/17	9/24+
Boraginaceae					
Coldenia canescens	—	6/1	7/10	8/11	—
C. hispidissima	—	6/1	7/10	8/17	—
Cryptantha angustifolia	4/7	—	5/15	—	6/26
C. jamesii laxa	5/15	6/29	7/10	—	—
C. jamesii setosa	4/9	—	6/15	7/31	9/24
Heliotropium convolvulaceum	2/5	4/7	5/15	6/12	9/24+
H. curassavicum	4/7	—	6/29	7/31	9/24+
H. greggii	2/5	4/7	6/29	6/29	9/24+
Lithospermum multiflorum	5/15	6/29	7/10	—	9/24+

Table 3.7 (cont)

Taxa	Dates of 1st growth	1st flowers	Max. flowers	Fruit mat.	Dormancy
Cactaceae					
Coryphantha macromeris	—	--	6/15	8/15	--
Echinocactus texensis	--	—	5/15	6/15	--
Echinocereus caespitosus					
E. fendleri					
Opuntia kleinise	5/15	5/15	6/1	6/13	9/24
O. leptocaulis	5/15	5/15	6/1	6/13	9/24
O. phaeacantha	4/7	4/7	6/1	5/15	9/24
Caryophyllaceae					
Paronychia jamesii	5/15	6/1	—	--	--
Chenopodiaceae					
Atriplex canescens	4/7	5/15	—	9/22	9/24+
Chenopodium desiccatum	5/15	7/17	7/31	8/17	9/24+
C. hians	5/15	7/17	7/31	8/17	9/24+
C. incanum	5/15	6/26	7/31	8/17	9/24+
Cycloloma atriplicifolia	5/15	7/31	8/17	—	9/24+
Salsola kali tenuifolia	4/7	7/31	7/31	8/17	9/24+
Commelinaceae					
Commelina dianthifolia	4/7	—	6/13	8/17	9/24+
C. erecta angustifolia	4/7	7/18	--	—	9/24+
Tradescantia occidentalis	4/7	—	6/15	—	9/24+
Compositae					
Ambrosia artemisiifolia	4/7	5/15	6/15	--	9/24+
Aphanostephus ramosissimus	2/5	4/7	6/12	7/10	9/24
Artemisia filifolia	2/5	9/8	9/24	—	9/24+
A. ludoviciana	4/7	8/11	9/9	9/9	9/24+
Baccharis wrightii	4/7	—	7/10	8/3	9/24+
Bahia pedata	5/15	6/28	7/10	—	9/24+
Baileya multiradiata	5/15	6/15	8/14	8/14	9/24+
Chrysothamnus pulchellus	5/15	—	7/31	8/15	9/24+
C. spathulatus	--	--	8/15	9/8	9/24+
Cirsium spp.	5/15	--	--	--	--
Conyza coulteri	6/15	—	--	9/9	9/24
Dyssodia pentachaeta hartwegii	5/15	6/26	--	--	--
Erigeron bellidiastrum	4/7	5/15	6/15	6/31	9/24
Flourensia cernua	6/26	9/8	9/24	—	9/24+
Franseria confertiflora	4/7	8/14	—	--	--
Gaillardia pinnatifida	4/7	7/17	7/31	8/17	--
G. pulchella	4/7	—	6/15	6/26	—
Gutierrezia microcephala	7/31	9/9	9/24+	—	9/24+
G. sarothrae	7/31	9/22	--	--	9/24+

Table 3.7 (cont)

Taxa	Dates of 1st growth	1st flowers	Max. flowers	Fruit mat.	Dormancy
Haplopappus spinulosus australis	2/5	4/7	7/17	7/17	9/24+
H. spinulosus glaberrimus	2/5	4/7	7/17	7/17	9/24+
H. spinulosus scabrellus	2/5	5/15	6/26	—	9/24+
Helianthus petiolaris	4/7	7/19	9/8	9/22	9/24+
Heterotheca psammophila	5/15	—	9/9	—	9/24+
Hymenopappus flavescens	2/5	9/8	8/15	—	—
Hymenoxys scaposa glabra	5/15	—	6/15	7/31	—
H. scaposa scaposa	5/15	—	6/15	7/31	—
Machaeranthera tanacetifolia	4/7	6/15	7/10	—	—
Melampodium cinereum	2/5	4/7	5/17	6/26	9/24+
M. leucanthum	2/5	4/7	5/17	6/26	9/24+
Palafoxia sphacelata	4/7	5/15	6/26	—	—
Parthenium confertum	4/7	6/29	8/17	—	9/24+
Pectis angustifolia	2/5	5/18	6/15	7/10	7/31
Perezia nana	8/3	—	9/9	—	9/24+
P. wrightii	—	—	7/21	—	—
Psilostrophe tagetina	4/7	6/15	7/21	7/31	—
P. villosa	2/15	6/15	6/11	—	—
Leucelene ericoides	2/5	4/7	7/31	8/14	9/24+
Ratibida tagetes	—	7/17	—	8/14	—
Sartwellia flaveriae	—	6/26	—	—	—
Senecio multicapitatus	4/7	6/15	8/14	9/9	9/24+
Stephanomeria pauciflora	—	5/18	9/9	9/8	—
Thelesperma megapotamicum	4/7	6/29	8/14	—	9/24+
Verbesina encelioides	4/7	6/29	8/14	—	9/24+
Xanthocephalum texanum	—	6/13	8/14	9/9	9/24+
Zinnia grandiflora	5/15	7/31	8/14	9/10	9/24+
Convolvulaceae					
Cuscuta leptantha	—	7/31	—	—	—
Evolvulus nuttallianus	—	6/12	—	—	—
Cruciferae					
Descurainia pinnata halictorum	2/5	4/7	5/15	6/26	9/24
Dithyrea wislizenii	2/5	4/7	5/15	6/26	9/24
Greggia camporum linearifolium	2/5	5/15	6/15	7/12	9/24
Erysimum asperum	4/7	6/12	6/26	7/10	9/24
Greggia camporum	2/5	5/15	6/15	7/12	9/24
Lepidium virginicum medium	4/7	6/10	7/10	7/31	9/24
Lesquerella fendleri	2/5	4/7	5/15	6/10	9/24
Cucurbitaceae					
Cucurbita digitata					
Cucurbita foetidissima	4/7	7/10	—	9/8	9/24
Ibervillea tenuisecta	5/15	6/26	—	9/24	9/24
I. tripartita	5/15	—	7/19	—	9/24

Table 3.7 (cont)

Taxa	Dates of 1st growth	1st flowers	Max. flowers	Fruit mat.	Dormancy
Cyperaceae					
Cyperus schweinitzii	4/7	6/12	--	--	9/24+
Euphorbiaceae					
Croton dioicus	4/7	6/12	7/10	7/10	9/24+
C. glandulosa lindheimeri	--	--	--	9/9	9/24+
C. texensis	4/7	6/14	7/10	9/9	9/24+
Ditaxis neomexicana	5/15	--	--	9/9	9/24+
Euphorbia fendleri	2/5	4/7	5/15	6/12	9/24
E. glyptosperma	4/7	6/12	--	7/10	--
E. lata	4/7	5/15	6/12	8/14	--
E. missurica	4/7	5/15	6/12	8/14	--
E. serpens	4/7	5/15	6/12	7/10	9/24
E. serpyllifolia	4/7	7/10	7/31	8/14	9/24+
E. serrula	4/7	7/10	7/31	8/14	9/24
Phyllanthus abnormis	--	6/12	7/31	--	9/24
Reverchonia arenaria	--	6/12	6/19	--	--
Tragia stylaris	4/7	5/15	--	--	--
Ephedraceae					
Ephedra torreyana	4/7	5/15	--	--	9/24+
Fagaceae					
Quercus havardii	4/7	4/7	4/7	none	9/24+
Gentianaceae					
Centaurium calycosum breviflorum	--	5/15	6/15	--	--
Gramineae					
Andropogon barbinodis	5/15	7/10	7/10	--	9/24+
Aristida longiseta	4/7	5/15	6/12	7/31	9/24
A. purpurea	4/7	5/15	6/12	7/31	9/24
A. wrightii	--	5/15	6/12	7/31	9/24
Bouteloua barbata	5/15	6/12	6/26	--	8/14
B. curtipendula	--	7/10	--	--	--
B. eriopoda	5/15	6/12	6/26	8/14	9/24+
B. hirsuta	5/15	6/12	6/26	8/14	9/24+
Brachiaria ciliatissima	--	--	7/31	--	--
Cenchrus incertus	4/7	--	--	6/26	9/24+
Chloris cucullata	4/7	--	6/12	6/26	--
Eragrostis arida	--	--	8/1	--	9/24
Eragrostis secundiflora	5/15	6/12	6/26	8/14	9/24
Hilaria mutica	--	--	7/31	--	9/24
Leptoloma cognata	4/7	5/15	6/15	7/17	9/8
Muhlenbergia porteri	4/7	5/15	6/13	7/10	9/24

Table 3.7 (cont)

Taxa	Dates of 1st growth	1st flowers	Max. flowers	Fruit mat.	Dormancy
M. torrevi	—	5/15	6/13	7/10	9/24
Munroa squarrosa	2/5	5/15	5/26	—	8/14
Panicum capillare	2/5	5/15	6/12	7/10	9/24
P. obtusum	—	—	—	7/17	—
Paspalum setaceum	4/7	—	—	—	—
Scleropogon brevifolius	7/17	8/14	9/8	9/22	9/24+
Setaria leucophila	—	—	6/26	—	—
S. macrostachya	4/7	5/15	6/26	7/10	9/24
Sporobolus cryptandrus	5/15	6/26	7/31	—	—
S. giganteus	5/15	6/26	7/31	—	—
Trichachne california	—	—	6/26	—	—
Tridens pulchellus	5/15	6/26	—	—	9/24
Triplasis purpurea	7/31	—	—	—	—
Hydrophyllaceae					
Phacelia corrugata	4/7	5/15	6/12	6/12	9/24+
P. integrifolia	2/5	4/7	5/15	6/12	9/24+
Koeberliniaceae					
Koeberlinia spinosa	—	—	6/15	8/1	9/24+
Labiatae					
Monarda punctata lasiodonta	2/5	4/7	5/15	6/26	9/8
Scutellaria drumondii	2/5	4/7	5/15	—	—
Leguminosae					
Acacia constricta	—	5/15	6/12	9/8	9/24+
Cassia bauhinioides	—	—	5/15	—	—
Dalea formosa	4/7	5/15	5/26	—	9/24+
D. lanata	4/7	6/15	6/26	7/31	9/24
Hoffmanseggia jamesii	4/7	5/15	6/15	—	—
Krameria lanceolata	—	5/15	6/12	—	—
K. glandulosa	—	—	5/15	7/26	—
Prosopis glandulosa	4/7	5/15	6/12	7/10	9/24+
Linaceae					
Linum aristatum	—	5/15	6/26	7/31	—
L. aristatum australe	—	4/7	6/29	7/31	—
Loasaceae					
Cevallia sinuata	—	—	—	—	—
Mentzelia humilis	4/7	5/15	6/12	—	—
M. reverchonii	2/5	4/7	5/15	6/26	9/24

Table 3.7 (cont)

Taxa	Dates of 1st growth	1st flowers	Max. flowers	Fruit mat.	Dormancy
M. strictissima	2/5	4/7	5/15	7/10	9/24
Malvaceae					
Sida physocalyx	--	--	6/26	—	--
Sphaeralcea coccinea	2/5	5/15	6/26	7/31	--
S. digitata	2/5	4/7	6/15	7/10	—
S. subhastata	4/7	7/10	7/26	9/9	--
Martyniaceae					
Proboscidea sabulosa	4/7	—	7/21	—	--
Nyctaginaceae					
Abronia fragrans	2/5	4/7	5/15	6/26	9/24+
Acleisanthes longiflora	--	—	7/21	--	--
Ammocodon chenopodioides	—	--	--	--	--
Boerhaavia intermedia	—	6/26	--	--	--
Oxybaphus linearis decipiens	4/7	5/15	6/26	--	--
Selinocarpus diffusus	--	--	6/29	--	--
Oleaceae					
Mendora scabra ramosissima	—	--	6/26	—	--
Onagraceae					
Calylophus hartwegii pubescens	2/5	4/7	5/15	--	9/24+
C. serrulatus	--	—	6/12	—	9/12+
Gaura villosa	--	5/15	6/12	—	--
Oenothera albicaulis	--	—	6/28	--	--
O. biennis centralis	--	--	6/29	—	--
O. neomexicana	--	--	--	--	--
Orobanchaceae					
Orobanche multiflora	4/7	5/15	6/12	7/10	7/31
Polemoniaceae					
Ipomopsis longiflora	—	--	6/26	—	—
I. pumila	—	5/15	6/15	7/26	9/24+
Polygonaceae					
Eriogonum leptocladon	4/7	7/31	9/8	—	9/24+
E. rotundifolium	4/7	5/15	6/26	8/14	9/24+

Table 3.7 (cont)

Taxa	Dates of 1st growth	1st flowers	Max. flowers	Fruit mat.	Dormancy
Polypodiaceae					
Notholaena sinuata	—	--	--	--	--
Portulacaceae					
Portulaca parvula	—	7/10	8/14	—	--
P. retusa	—	7/10	8/14	--	--
Talinum angustissimum	4/7	—	6/15	7/10	—
Rhamnaceae					
Condalia ericoides	—	4/7	5/15	6/12	9/24+
Zizyphus obtusifolia	4/7	6/12	6/26	7/31	9/24+
Rubiaceae					
Houstonia humifusa	2/5	4/7	5/15	6/12	8/14
Rutaceae					
Thamnosma texana	--	4/30	--	--	--
Sapindaceae					
Sapindus drummondii	4/7	--	5/15	—	9/26+
Scrophulariaceae					
Castilleja sessiliflora	—	--	6/26	7/31	9/8
Linaria texana	--	—	5/17	--	--
Maurandya vislizenii	4/7	5/17	6/12	7/10	—
Penstemon ambiguus	4/7	5/15	6/14	7/31	--
P. fendleri	2/5	4/7	—	5/15	7/31
Solanaceae					
Chamaesaracha conioides	—	—	6/29	—	--
Lycium berlandiera	6/15	--	—	—	9/24+
Nicotiana trigonophylla	—	--	6/15	7/10	—
Physalis lobata	5/15	6/12	6/29	7/31	--
P. hederaefolia cordifolia	5/15	—	9/9	—	—
Solanum elaeagnifolium	4/7	6/12	6/26	9/8	9/24
Solanum rostratum	—	--	7/20	—	--
Ulmaceae					
Celtis reticulata	—	--	7/21	--	--
Umbelliferae					
Eurytaenia texana	—	--	5/17	—	--

Table 3.7 (cont)

Taxa	Dates of				
	1st growth	1st flowers	Max. flowers	Fruit mat.	Dormancy
Verbenaceae					
Aloysia wrightii	--	--	9/9	--	9/24+
Tetraclea coulteri	--	--	6/26	--	--
Verbena bracteata	4/7	6/12	6/26	7/31	9/24
V. ciliata	4/7	--	6/15	7/31	9/8
V. plicata	4/7	6/15	6/29	--	9/24
V. wrightii	4/7	--	6/26	9/9	9/24+
Violaceae					
Hybanthus verticillatus	--	--	5/18	--	--
Zygophyllaceae					
Kallstroemia grandiflora	5/15	7/10	8/1	--	--
Larrea tridentata	4/7	5/15	6/12+	7/12	9/12+
Tribulus terrestris	5/15	7/10	8/14	9/8	9/24+

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CHAPTER 4

SOILS AND PLANT PRODUCTIVITY STUDIES

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Introduction

The general objectives of the soils and plant productivity investigations are to provide baseline data on soils and vegetation of the area and to provide information which may be utilized to develop models of nutrient cycling and plant productivity in this ecosystem. Because of the aridity of the area, water is undoubtedly the major factor controlling the composition of plant communities and productivity. However, in addition to meteorological factors, including precipitation, solar radiation, and temperature, soil factors play a major role in regulating plant community development and productivity. While soil properties are of major importance in determining water availability, nutrieut limitations--most likely nitrogen or phosphorus--may constrain plant productivity at the occasional times when water is not limiting. Hence a detailed study of soil nitrogen and phosphorus was initiated to provide data that can be utilized in developing models of nitrogen and phosphorus cycling in these communities. Other physical and chemical soil characteristics were determined for use in the cycling of elements and for predicting the movements of introduced radionuclides through the ecosystem.

This report describes the characteristics of the major soil series of the Los Medaños area. It also presents the initial results from a much more detailed study of soils and vegetation at permanent sites. These study sites were established in a *Prosopis glandulosa*-*Quercus havardii* (honey mesquite-shinnery oak) community located on a sandy soil,[1] and a

Larrea tridentata (creosotebush) community located on a shallow, calcareous soil.[1] At these study sites, data were collected on the soil's physical and chemical properties as related to vegetative cover and plant-soil water relations under field conditions. The vegetation studies included a description of plant community composition, and a determination of the amount of standing biomass in the study areas, by species and plant component. Future objectives at these study sites include measurement of nutrients in the vegetative biomass and study of the dynamics of nutrient transfer between plant biomass, litter, and soil.

Materials and Methods

Soils Investigations

Study Sites and Soil-Sampling Procedures -- A map of the WIPP site and the surrounding Los Medaños area is shown as Figure 4.1. Soil samples were initially collected from the major soil series and complexes shown on Soil Conservation Maps[1,2] at locations designated on Figure 4.1 as sites 1 to 15. Surface and subsurface soil samples were taken at depths of 0 to 10 cm and 25 to 36 cm except in the shallow Simona series which, because of the consolidated caliche layer, was only sampled at a depth of 0 to 10 cm.

Permanent study plots were established in a mesquite-oak community (MO-1, MO-2) and a *Larrea* community (L-1, L-2) (Fig. 4.1). Each plot was 100 x 100 m and was subdivided into 100 quadrats of 10 x 10 m each. The mesquite-oak plots were located in the Berino soil complex, while the *Larrea* plots were located in the Simona soil series, according to the Soil Conservation Service map of Eddy County.[1] The replicate plots were located in close proximity of each other and were selected by visual estimation as typical of the surrounding plant communities.

Soil samples were taken from 10 randomly selected quadrats in each of the four permanent plots. In each quadrat in the mesquite-oak community, samples were taken in an open area under the canopy of oak, and

usually under the canopy of a mature mesquite. In the MO-1 plot, the three soil samples were located within or occasionally just outside the designated quadrat. In the MO-2 plot the nearest mature mesquite was sufficiently distant from seven of the selected quadrats that soil samples in these seven quadrats were obtained near the base of a mature Artemisia filifolia (sagebrush) instead of mesquite. Soil samples were usually obtained using a soil auger at depths of 0 to 10, 10 to 46, 46 to 70, and 70 to 100 cm in the mesquite-oak study area; however, when soil moisture was especially low it was necessary to use a shovel to obtain samples due to the sandy nature of the soil.

At each Larrea study plot, soil samples were collected in an open area and under a mature Larrea in 10 randomly selected quadrats. Because of the shallow nature of the soil at these sites, samples were generally obtained with a shovel and were limited to depths of 0 to 10 cm and 10 cm to the caliche layer which usually varied from 15 to 25 cm beneath the surface.

Soil samples collected for both the general survey and from the permanent study plots were returned to the laboratory and air dried. Soil samples were sieved through a 2-mm screen and thoroughly mixed prior to analysis. Composite soil samples, representative of each study plot, were prepared by mixing equal volumes of sieved soil from all quadrats sampled at the study plot from a particular vegetation type and depth.

Soil Characteristics -- The soil's chemical and physical characteristics were determined on duplicate subsamples of each sieved soil sample or composited sample; however, the water retention characteristics of composited soil samples were determined on triplicate subsamples.

Mineral soil particles coarser than 2 mm were weighed after sieving and their weight expressed as a percentage of the total soil sample. Soil particle analysis was conducted by the hydrometer method.[3] Soil water retention was measured at field capacity (-0.3 bar) and at the commonly used permanent wilting point (-15 bars) by a pressure membrane apparatus.[4] The percentage of available water was estimated as the difference between

the soil water content at field capacity and the permanent wilting point. The nitrogen content of soil samples (excluding nitrate and nitrite) was determined by the semimicro Kjeldahl procedure.[5] Phosphorus was extracted from soil samples with 0.5 N $NaHCO_3$ at pH 8.5 and measured colorimetrically.[6] Soil organic matter was determined by the Walkley-Black chromic acid oxidation method using a factor of 1.30 to correct for incomplete oxidation of organic matter.[7,8] Soil organic carbon was computed by multiplying the percentage of organic matter by a factor of 0.58.[9] Cation exchange capacity of soil samples was determined by the sodium saturation method.[10] Soil pH was determined on saturation paste samples.[7] The electrical conductivity of saturation paste extracts was measured using a conductivity cell.[11] Calcium, magnesium, potassium, and sodium were determined in the saturation paste extract. A more detailed description of the analytical methods used is given by Johnson et al (1979).[12]

Plant and Soil Water Relation -- Soil water content of field collected soil samples were determined gravimetrically in conjunction with plant water status measurements from May through September 1978. Plant water status was measured as the xylem pressure potential using a pressure bomb (PMS Instrument Company, Corvallis, Oregon).[13] Pressure potential measurements were made on shrubs at (or near) dawn and again at various times throughout the day. In general, three apical stem sections, 2 to 5 cm in length, were selected to obtain an average pressure potential value for individual shrubs. Healthy stem sections with leaves were used; however, samples were randomly selected in regard to position on the shrub. Measurements were ordinarily made on two shrubs of each species at the mesquite-oak study site and three replicates of each species at the *Larrea* study sites.

The resistance of oak leaves to the diffusion of water vapor was measured as an indication of stomatal apertures, and hence, an indication of transpiration using a diffusive resistance meter (Lamba Instrument Co., Lincoln, Nebraska).[14] Diffusive resistance measurements were made simultaneously with pressure potential measurements on two oak clones shortly

after dawn and at several times during the day. Diffusive resistance measurements were made on the lower surface of three healthy leaves without regard to position on the plant.

Plant Productivity Investigations

Field and Laboratory Procedures -- Total and relative cover values were determined using four or five randomly selected 60-m line-intercept transects on each of the four 1-ha plots in the mesquite-oak community (MO-1 and MO-2) and in the *Larrea* community (L-1 and L-2). The four or five transects in each plot were pooled and species-cover-per-hectare was estimated.

Total harvests of important shrub, forb, and grass species were made in the two communities. Individual specimens were selected for typical canopy form and for variation in size. The maximum height and the average of the largest and smallest diameters were determined for each specimen prior to excavation. Woody species were separated into component parts and the individual pads of *Opuntia phaeacantha* (prickly-pear) were measured and likewise separated. All specimens were placed in paper sacks for transport and subsequent drying.

In the laboratory, the plant material was dried in ovens set at 90°C for three days or until constant weight was achieved. Samples were weighed and recorded to the nearest 0.1 g.

Data Analysis -- Root-to-shoot and total-to-plant component ratios of three species were calculated for future use in estimating total biomass by component per hectare. Biomass values were plotted against the canopy area to obtain a predictive relationship between the two parameters. The calculated slopes and intercepts were used to develop equations that would estimate standing biomass as a function of canopy cover.

Results and Discussion

Soils Investigation

General Survey -- Soil profile characteristics, general surface features, and plant communities of the Los Medaños are described in some detail in Soil Conservation Service reports[1,2] and in a WIPP progress report by Wolfe et al.[15] Chemical and physical characteristics of soil samples collected in a general survey of the major soil series of the Los Medanos area are tabulated in Tables 4.1 through 4.4. In Table 4.1 the light texture of all the soils of the area is evident. Soils of the Berino complex and Kermit and Pyote series are classified as sands while most samples of the Pajarito, Wink, and Simona series and the Simona-Bippus complex range from loamy sands to sandy loams. The Simona series and Simona-Bippus complex are characterized by significant amounts of gravel and rocks coarser than 2 mm. The sandy nature of most soils of the Los Medaños area is predictive of very low soil organic matter contents and nutrient levels including nitrogen and phosphorus. In addition, the predominance of coarse textured soils is of great significance in soil-plant-water relations.

Water retention characteristics are listed in Table 4.2. In the very sandy Berino complex and Kermit soils, very low water contents were obtained at field capacity (matrix potential of -0.3 bar) and at the permanent wilting percentage (matrix potential of -15 bars). Even small increases in the silt and clay content in these soils resulted in appreciable increases in the net available water between field capacity and the permenant wilting percentage, as noted at sites 3 and 6, compared to other Berino complex samples in Tables 4.1 and 4.2. Soil samples obtained under mesquite in the Berino complex (site 8) and Kermit soil (site 4) retained more available water than adjacent sites with the same texture, probably due to the higher organic matter content in the soils under mesquite (Table 4.3). Soil samples obtained under mesquite in the Pajarito series retained less available water than in the adjacent open area, a difference which is attributed in these samples to the lower clay content under mesquite compared to the open site. The low water content

at the permanent wilting point for the sandy soils indicates that most soil moisture would be readily available to plant roots. Even though many native plants of the Los Medaños area undoubtedly are able to absorb water at matrix potentials below the conventional permanent wilting point, very little additional water could be obtained from the sandy soils. Considerably deeper water penetration would occur following appreciable rainfall on the extremely sandy soils compared to the somewhat finer textured Pajarito, Wink, Simona, and Simona-Bippus complex soils. Organic matter, carbon, total nitrogen content, the carbon nitrogen ratio, and extractable phosphorus for soils of the Los Medanos area are listed in Table 4.3.

As expected, soil organic matter and nitrogen are quite low in the sandy soils and higher in the finer textured soils from open sites except for the Pajarito soil (site 10). The 0-to-10-cm soil samples collected under mesquite have appreciably higher organic matter and total nitrogen content than soil samples from adjacent open areas. This effect of mesquite on soil properties is evident in samples from 25 to 36 cm as well at sites 4A and 10A. The carbon nitrogen ratio ranges from about 4 to 13.7 with a surprising number of samples between 5 and 7. The carbon-nitrogen ratio was not consistently different in samples taken from underneath mesquite compared to adjacent open sites. The relatively low carbon-nitrogen ratios suggest that with adequate soil moisture, nitrogen would be released for utilization by plant roots rather than immobilized by soil microorganisms.[16] Extractable phosphorus was much higher in samples of the Berino complex and Kermit soil collected under mesquite than in adjacent open areas (sites 4 and 4A, 8 and 8A) at both depths sampled.

Several other chemical properties of the soils of the Los Medaños area are tabulated in Table 4.4. Most soil pH values range from 7 to 8; however, soil samples obtained under mesquite from the Berino and Kermit soils had pHs ranging from 6.1 to 6.6, while samples under mesquite in the Pajarito soil had slightly higher pH's than samples from an adjacent open site. Cation exchange capacities of the sandy soils were quite low (2.5 to 5.0 meq/100 g) with values ranging up to 13.2 meq/100 g in the soils with higher clay contents. It should be noted that these measurements

were made on air-dry samples and hence may overestimate the actual cation exchange capacity.[23] The measurements on saturation paste extracts indicate that neither soil salinity nor excessive soluble sodium is a problem at the sites sampled. The effect of mesquite on soil properties is again apparent as several fold increases in electrical conductivity and soluble potassium, calcium, and magnesium is noted under mesquite compared to adjacent open areas. Soluble sodium, however, was essentially unaffected by the mesquite.

Tiedemann and Klemmedson (1973b)[18] reported that in the Sonoran desert, the surface--4.5 cm of soil under Prosopis juliflora (velvet mesquite)--had up to three times more organic matter, total nitrogen, total sulfur, and total soluble salts than soil from nearby open areas. Subsequently Barth and Klemmedson (1978)[19] presented data showing that soil under honey mesquite in the Chihuahuan Desert near Las Cruces, New Mexico, also had a higher organic carbon and total nitrogen content than soil from adjacent open areas. The soil pH increased with distance from the center of the canopy of velvet mesquite; however, pH was not considered to be significantly altered from that in open areas by honey mesquite.

Soil Characteristics at the Permanent Study Areas -- We planned to analyze all soil samples from 10 quadrats of each plot representing open areas and the dominant shrubs at all depths sampled for total nitrogen and extractable phosphorus to obtain measures of variability within each plot and between replicate plots in the two-plant communities. The analyses of soil samples from the two mesquite-oak plots and the two Larrea plots for total nitrogen are reported in Table 4.5. Results of phosphorus analyses for study plots MO-1, L-1, and L-2 are tabulated in Table 4.6; analyses for plot MO-2 have not yet been completed. Duncan's multiple range test was used to determine significant differences ($P = 0.05$) in soil properties at different depths in open and shrub covered areas and between the paired permanent plots in each plant community. Duncan's test was applied only to properties measured on samples from 10 quadrats in a plot. Total nitrogen analyses in Table 4.5 indicate reasonable uniformity of soil samples from different quadrats within each study plot from similar depths

and vegetational influences. No statistically significant differences in mean soil nitrogen content were found in comparisons of samples from the same depth and vegetation areas collected from sites MO-1 and MO-2 or from sites L-1 and L-2.

Table 4.5 indicates that surface soil samples obtained under mesquite have significantly higher total nitrogen content than surface samples from open areas in site MO-1. The 0-to-10-cm sample under oak also had a significantly higher nitrogen content than samples from open areas in site MO-1; however, the nitrogen content at this depth under oak was only about half that under mesquite. The nitrogen content under mesquite and oak is significantly greater than in open areas only at a depth of 0 to 10 cm, decreases at a depth of 10 to 46 cm, and approaches values for open areas at 46 to 70 cm. The nitrogen content does not decrease significantly with depth in samples from open areas in the mesquite-oak community.

The nitrogen content of soil samples collected from beneath Larrea did not differ significantly from soil collected from similar depths in open areas in study sites L-1 and L-2. The nitrogen content of the Simona soil tends to increase at a depth of 10 to 25 cm compared to the 0-to-10-cm depth.

Soil nitrogen contents in surface samples from open areas in the mesquite-oak plots averaged 0.012% and in the Larrea plots 0.07%. These values are quite low, as would be expected for light textured soils developed under warm, arid conditions.[16]

Extractable phosphorus data in Table 4.6 are somewhat more variable than total nitrogen data, especially in samples beneath Larrea at site L-2. Although extractable phosphorus values beneath Larrea at site L-2 did not differ consistently from samples from open areas in the Larrea community, the values beneath Larrea tended to decrease below the 0-to-10-cm depth in both communities sampled. The values of extractable phosphorus did not differ significantly between surface samples from sites L-1 and L-2 either, but the values were much higher in the 0 to 10 sample

under mesquite than in samples from beneath oak or open areas. The phosphorus concentration under mesquite, oak, and in open areas did not differ significantly below the 10-cm depth.

The $NaHCO_3$ extractable phosphorus from surface samples in open areas averaged 1.8 $\mu g/g$ at the MO-1 site and 7.4 $\mu g/g$ at the L-1 and L-2 sites. Both these values indicate a very low phosphorus status. Jackson states that in agricultural soils a crop response to phosphorus fertilization is likely at 5 $\mu g/g$ or lower $NaHCO_3$ extractable phosphorus.[7]

In an attempt to identify other influences of the dominant shrubs on soil properties, analysis for organic matter (and hence, organic carbon) was conducted on all samples from sites MO-1, L-1, and L-2 (Tables 4.7, 4.8). Additionally, pH measurements were made on all samples from sites MO-1 and L-1 (Table 4.9). Data for organic matter, organic carbon, total nitrogen, carbon nitrogen ratio, and extractable phosphorus for sites MO-1, L-1, and L-2 are summarized in Table 4.10.

Thus, organic matter and organic carbon contents are three-fold higher in the 0-to-10-cm surface soil under mesquite than in open areas at site MO-1 (Tables 4.7, 4.8). While mean organic matter contents at depths of 10 to 46 cm and 46 to 70 cm under mesquite were higher than in comparable samples from open areas, these differences were not significant ($P = 0.05$). Soil samples from under oak also had significantly higher organic matter (and organic carbon) contents than samples from open areas at a depth of 0 to 10 cm; however, the organic matter content under oak was only about half that measured under mesquite. At the L-1 and L-2 sites, the organic matter and organic carbon content of soil samples obtained under Larrea did not differ from open area samples. At site L-2, significantly higher organic matter and organic carbon content occurred below 10 cm compared to the 0-to-10-cm sample. Most carbon-nitrogen ratios were close to 10 for samples from the mesquite-oak study site regardless of the vegetation cover or soil depth (Table 4.10). Carbon nitrogen ratios at the Larrea study sites ranged from 7.0 to 9.7. Thus, the carbon-nitrogen ratio was close to equilibrium for soil organic matter in both study areas.[16]

Soil pH values in the surface samples (0 to 10 cm) from the MO-1 site were considerably lower under mesquite than in open areas where it averaged 7.02 (Table 4.9). Mesquite, however, did not have a significant effect on soil pH at greater depths. Soil pH under oak did not differ significantly from that at open sites. Larrea did not alter soil pH from that of open areas in plot L-1, which averaged 8.25. Soil pH values for composite samples in Table 4.11 indicate that the MO-2 site mesquite had only a slight effect on soil pH; however, this represents samples from under only three mesquite. The pH values for composite samples from the L-2 site are slightly lower under Larrea than in open areas.

The effects of mesquite on properties of the Berino complex soil observed in this investigation are similar to the reports of increased organic matter, carbon, and total nitrogen beneath honey and velvet mesquite.[19,20] Additionally, we found surface soil pH to be markedly lower and extractable (available) phosphorus to be higher than in adjacent open areas. These characteristics of the Berino complex soil suggest increased fertility and potential for productivity in soil under the canopy of mesquite based on greenhouse studies of soils from a velvet mesquite community in the Sonoran Desert.[18]

The results of mechanical analyses, the soil textures of composite samples, and the number of samples comprising each composite sample are shown in Table 4.12. All samples from the mesquite-oak study sites were classified as sands while samples from the Larrea study sites were classified as loamy sands and sandy loams. The percentage of gravel and rocks in samples from open sites is considerably greater than in samples from under Larrea. This difference may possibly be attributed to the trapping of wind-blown soil by the understory vegetation occurring beneath most of Larrea.

Water retention characteristics of composite soil samples are tabulated in Table 4.13. The percentage of available water (between -1/3 and -15 bars) retained by the sandy Berino complex soil from site MO-1 under mesquite and oak is higher at the 0-to-10-cm depth (6.27% and 5.90%,

respectively) and at the 10-to-46-cm depth (4.13% and 4.58%, respectively) than in open areas where available water retention was as low as 1.35% and 2.86% at these depths. The higher water retention capacity of soils under mesquite and oak is attributed to the greater organic matter content under the shrubs compared to that in open areas. Deeper soil samples either from under shrubs or in open areas retained up to 6.83% available water, suggesting increased numbers of small soil pores at greater depth. The values reported in Table 4.13 for open areas at sites MO-1 are similar to values reported in the 1977 WIPP progress report;[15] however, much more available water is shown to be retained in the soil beneath mesquite and oak.

Variation between samples in retention of net available water at sites L-1 and L-2 is greater than would be expected, considering the rather uniform loamy-sand to sandy-loam texture of these soils (Table 4.1[illegible], 4.13). Greater water retention by some samples at a depth of 10 to 25 cm than at 0 to 10 cm is correlated with a higher organic matter content in the deeper sample. Considerably more water remains in the Simona soil at the classical permanent wilting percentage (-15 bars) than in the lighter-textured Berino complex soil. Significant amounts of water would undoubtedly be absorbed from the Simona soil by the drought-adapted species of the community until soil water potential was reduced to -60 bars or lower.

Soil crusts are especially well developed on the Simona soil of the *Larrea* study area and, although weakly developed, they occur on the Berino complex soils of the mesquite-oak study sites. Various soil crust samples from the L-1 study site have been characterized as consisting of either lichens or mixtures of green and blue-green algae (see Chapter 7 of this report). Results of analyses of two lichen crust samples from the L-1 site are given in Table 4.14. The surface lichen crusts, about 0.3 cm in thickness, were removed and are compared to the soil (subsurface) immediately below the crusts to a depth of 2.5 cm. The crusts are shown to be enriched in organic matter, organic carbon, and nitrogen compared to the subsurface immediately below. Measurements of the subsurface are comparable to values for the 0-to-10-cm samples at the L-1 site (Table 4.10).

The possibility of significant nitrogen fixation activity by blue-green algal soil crusts will be tested in future experiments.

Plant and Soil Water Relation -- The average annual precipitation for the Los Medaños area is 33 cm.[15] Monthly precipitation and temperature data for the period of this study are tabulated in this report (see Chapter 1). Considering the limited moisture, high temperatures, and low humidities characteristic of much of the year, water is undoubtedly the most critical factor for plant survival and growth.

Soil water contents are given for various depths under mesquite, oak, and sagebrush and in an adjacent open area: for various sampling dates between May and September 1978 (Table 4.15). Soil water contents at the mesquite-oak site were, on most sampling dates, below the classical permanent wilting percentage (-15 bars soil water potential) which was found to correspond to soil water contents of 1.5-2.6% (Table 4.13). Certainly most plants of the Los Medaños area would be able to absorb water and grow at somewhat lower soil water potentials. Occasional rainfalls replenished the soil water content to some depth (e.g., June 15, 1978) or in only the surface 0 to 10 cm (e.g., June 27, 1978). The soil water content varied only slightly in samples collected under shrubs as compared to adjacent open areas. Soil samples were collected on September 23, 1978, during a period of prolonged gentle rainfall. The samples, to a depth of at least 25 cm, were probably near field capacity. The water content of these samples is similar to field capacity measurements on the MO-1 soils conducted in the laboratory (Table 4.13).

Data for soil water contents at the Larrea sites are given in Table 4.16. Most soil water contents were considerably below that corresponding to the classical permanent wilting point (3 to 6% as shown in Table 4.13), indicating soil water potentials far below -15 bars. Apparently rainfall between June 2 and June 16, 1978, resulted in a slight increase in soil water content. The data suggest that soil water contents under mesquite located on or adjacent to site L-2 tend to be slightly higher than soil water contents of open area or under Larrea. Mesquite occurs in a lower

area and probably receives some runoff water from the slightly higher Larrea-dominated areas. The samples collected from the 0-to-10-cm depth during a period of prolonged rainfall on September 22, 1978, probably were at or exceeded field capacity. Laboratory measurements of field capacity (Table 4.13) were just slightly above soil water contents of the 0-to-10-cm samples on this date.

Xylem pressure potentials (P) of the major shrub specials measured at varicus times during the day are shown in Figs. 4.2-4.7. Based on dawn P for mesquite, oak, and sagebrush, appreciable soil moisture was available June 1 and June 15, 1978 (cf. Table 4.15), and P ranged from -16 to -26 bars (Figs. 4.2, 4.3). On June 1, 1978, minimum P (most negative values of P corresponding to greatest water stress) was measured at 1330 h and P increased at 1800 h for all three species.

Measurements of P at site MO-1 on July 12 and 25 and August 25, 1978, indicate periods of significant water stress with dawn measurements ranging from -31 to -46 bars. These dates correspond to very low soil water contents (Table 4.15). Minimum values of P were measured at midday and, on some days, an increase in P occurred in late afternoon. Measurements of P at dawn showed close agreement among the three species; however, mesquite often showed the greatest decrease in P at midday (e.g., Fig. 4.2). These observations suggest that mesquite, oak, and sagebrush may utilize water from similar soil regions. Additionally, mesquite seems to be less effective in limiting transpirational water loss.

On September 23, 1978, soil moisture was near field capacity to a depth of 46 cm (Table 4.15) and dawn P-values ranged from -12 to -17 bars. Even with abundant soil moisture, heavy clouds, and high relative humidity, P decreased to -16 to -25 bars by 1300 h. On this day minimum P values were exhibited by mesquite. Honey mesquite has been reported to carry on active photosynthesis at P values below -40 bars.[21]

Measurements of P for Larrea on June 16, 1978, showed a decrease from -27 to -45 bars between dawn and 1030 h (Fig. 4.3). Soil moisture contents were reduced from the mid-June level in July and August 1978

(Table 4.16). On July 25, 1978, a dawn P-value of -62 bars decreased to -65 bars by midday and remained at this value through late afternoon (Fig. 4.5). On August 26, 1978, P was measured at -57 bars at 0700 h and decreased to -67 at 1300 h. Even at P values of -50 to -78 bars, limited net photosynthetic activity has been reported in Larrea.[22] On September 22, 1978, during a rainy period, soil water content was near field capacity and P increased from -32 bars at 0700 h to -28 bars at 1500 h (Fig. 4.7). Under more typical soil and atmospheric moisture conditions, Larrea in this study area, did not show the increase in P during the day.[23]

Measurements of P were made on mesquite growing on or near the L-2 site on three dates. On July 25 and August 26, 1978, soil moisture was very low; however, mesquite maintained P values 20 to 25 bars higher than Larrea at dawn and throughout the day (Figs. 4.5, 4.6). In moist soil on September 22, 1978, mesquite maintained a P value 10 to 12 bars more positive than Larrea (Fig. 4.7). Mesquite in this area seems to be able to utilize presumably deeper soil regions that are not utilized by Larrea and thus maintain a more favorable water balance than adjacent Larrea. In addition, there is evidence that mesquite is able to more effectively limit transpiration under water stress than is Larrea.[21]

Diffusive resistance (r_l) values and leaf temperatures measured with a diffusive resistance meter for oak leaves are tabulated in Table 4.17. Interpretation of these data is ambiguous because of changes in water stress, temperature, and light intensity having differential effects on stomatal resistance throughout the day.

Plant Productivity Investigations

The investigative approach involved the complete harvest of plant specimens representing the species present and a subsequent attempt at dimension analysis.[24,25] It was decided to estimate biomass as a function of canopy area since, in normal vegetation surveys, only species cover is measured. In addition, due to the time-consuming method of measuring plant height in large sampling areas, growth ring counts to estimate biomass were considered.[26] However, this method was later rejected because

of the destructive sampling that would be required in subsequent surveys and because of the prodigiously destructive ant activity, which partly hallowed out the truck centers of most of the Larrea sampled. The ant destruction precluded any accurate counting of growth rings.

The vegetation survey was performed to determine cover values for the important species present in the permanent study plots. Results of the line-intercept transects are presented in Tables 4.18-4.21.

Calculated ratios between various plant components of the woody species sampled are presented in Table 4.22. Because of time considerations, only aboveground harvests of Q. havardii were performed. A root-to-shoot ratio of 10:1 was used in the estimation of total oak biomass in this study.[27]

Plant biomass-canopy area equations were derived from the slope and intercept values calculated from the harvested specimens. Canopy area vs biomass for a number of species was plotted graphically to illustrate the relationship (Figs. 4.8 to 4.11). In the case of Larrea, one specimen was dropped from the calculations because of its nonconformity with the rest of the data; i.e., for the canopy area measured, the total biomass was extremely high. This is not to suggest that this outlier should be completely ignored, but rather that inclusion of it with the rest of the data would not contribute to the formulation of a simple equation that would give a reasonable estimate of standing biomass.

After an equation was derived, the observed biomass values were compared with the estimated values. The total net difference in biomass between observed (O) and estimated (E) was divided by the total canopy area (m^2) of the harvested specimens of the particular species. The resultant value (g/m^2) was subsequently subtracted from the equation coefficient and a new set of estimated values were calculated. The new total net difference between O and E was again divided by the total canopy area and entered into Table 4.23 along with the list of equations. Species canopy cover values were next entered into the biomass equations

and estimated species biomass was calculated. These values are presented in Tables 4.24-4.27.

The results of the field work and data analysis provide what is believed to be a reasonable estimate of the standing biomass at the four plots being studied in the soil and plant productivity investigation at the Los Medaños WIPP site. It is felt that for most of the species harvested, an adequate sampling was performed. For species in uneven-aged stands, there is an apparently large variation in mass independent of canopy area or volume. More harvest sampling in such cases may not be useful. It is possible that in uneven-aged stands, such as those of Larrea in L-1 and L-2, a ring-count method patterned after Chew and Chew (1965) would produce more accurate results.[26] Regardless, in comparing computed biomass values using equations suggested in this paper with values derived by Ludwig et al, and Donart (1978),[24,28] we find that our equations more nearly approximate observed values. It is also felt that any derived biomass equation can be considered valid only in the area in which the derivation data were collected. Any extrapolation to another area would be risky at best.

Summary

Soil samples were collected from the major soil series in the Los Medaños WIPP study area and analyzed for texture, organic matter, organic carbon, pH, cation exchange capacity, total soluble salts, and the cations in the saturation paste extract.

Soil and plant productivity were studied at four permanent study sites established in major plant communities in the area, mesquite-oak on the Berino soil complex site and Larrea (creosotebush) on the Simona soil site. The texture of the Berino complex soil is sandy and is characterized by very low levels of organic matter, total nitrogen, cation exchange capacity, and extractable phosphorus, as well as by a very low water-holding capacity. While the properties of soil samples from open areas or from under dominant shrub species on the paired mesquite-oak plots

were relatively uniform, significantly higher values for organic matter, organic carbon, total nitrogen, extractable phosphorus, and lower pH were found in surface soil samples under mesquite compared to soils from open areas. Surface soil samples from under oak also had a higher organic matter content and higher nitrogen content than soils from adjacent open areas.

The Simona soil at the Larrea study sites has a loamy-sand to sandy-loam texture and is very shallow with a caliche layer at 15 to 25 cm. While organic matter, total nitrogen, and extractable phosphorus are quite low, they exceed values measured at the mesquite-oak sites. Soil properties measured on samples from beneath Larrea did not differ from samples from adjacent open sites. The water-holding capacity is considerably higher in the Simona soil than in the Berino complex soil; however, the shallow soil depth restricts water availability in the former.

During much of the period of May to September, 1978, the soil moisture content was very low; this was associated with significant plant water stress as indicated by very negative P. Generally, dawn P were similar for mesquite, oak, and sagebrush at the mesquite-oak site. When P for Larrea and adjacent mesquite were compared, more favorable water balance was found in mesquite suggesting deeper and more extensive root penetration by this species. Infrequent rains during the summer increased soil water content and reduced plant water stress as indicated by less negative pressure potential measurements.

The vegetative cover of the common plant species was determined at each study site by line-intercept transects. Ratios between plant component biomass (root: live shoot, etc) were determined for Larrea, Gutierrezia, and Artemisia. Equations were developed for 15 plant species relating biomass to canopy area and from these equations, biomass of these species was estimated for each of the four study plots.

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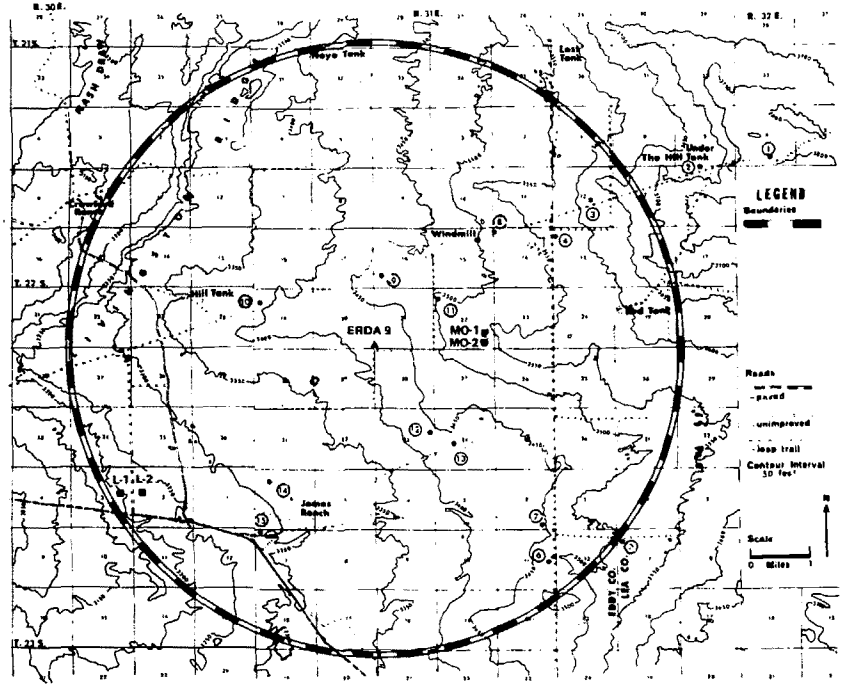

Symbol	Soil Series or Complex
1	Simona series
2	Pyote series
3	Berino complex
4	Kermit series
5	Wink series
6	Berino complex
7	Kermit series
8	Berino complex
9	Berino complex
10	Pajarito series
11	Berino complex
12	Berino complex
13	Berino complex
14	Berino complex
15	Simona-Bippus complex
MO-1, MO-2	Berino complex
L-1, L-2	Simona series

Fig. 4.1. WIPP site map showing location of initial survey sample sites (⊙•) and location of permanent study sites (■). Soil designations were taken from Soil Conservation Service Maps 1,2

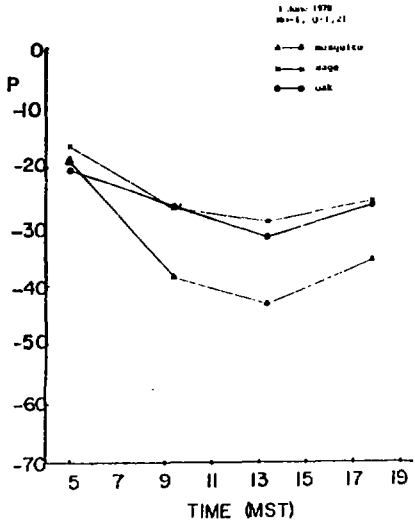

Figure 4.2. Xylem pressure potentials of shrubs from Study Site MO-1 1 June 1978.

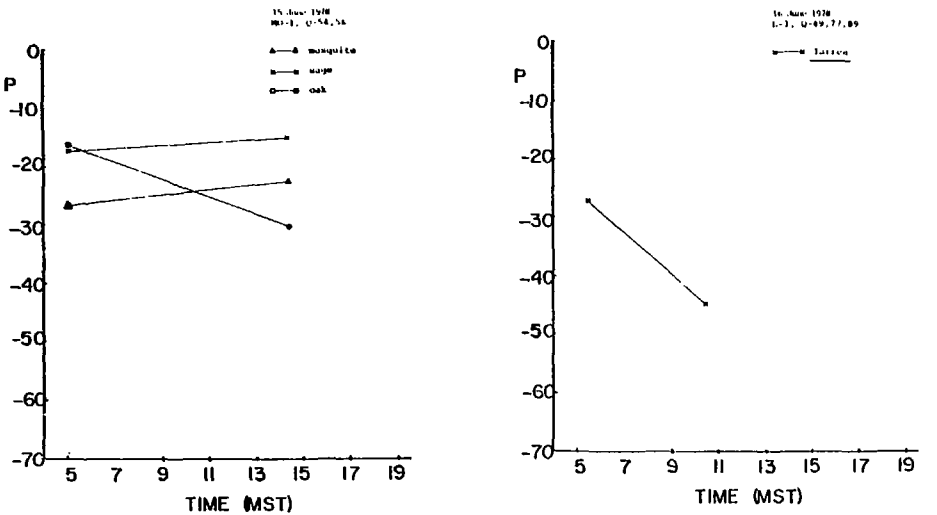

Figure [illegible] Xylem pressure potentials of shrubs from study sites MO-1 and L-1 15-16 June 1978.

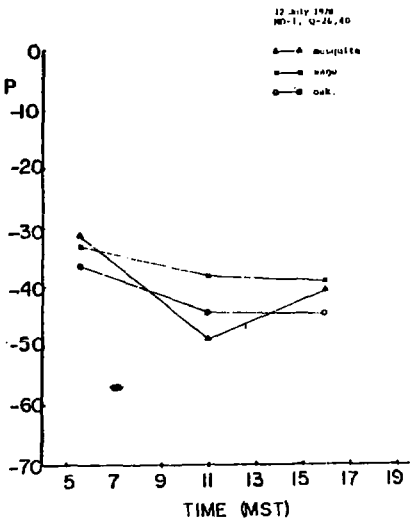

Figure 4.4. Xylem pressure potentials of shrubs from study sites 12 July 1978.

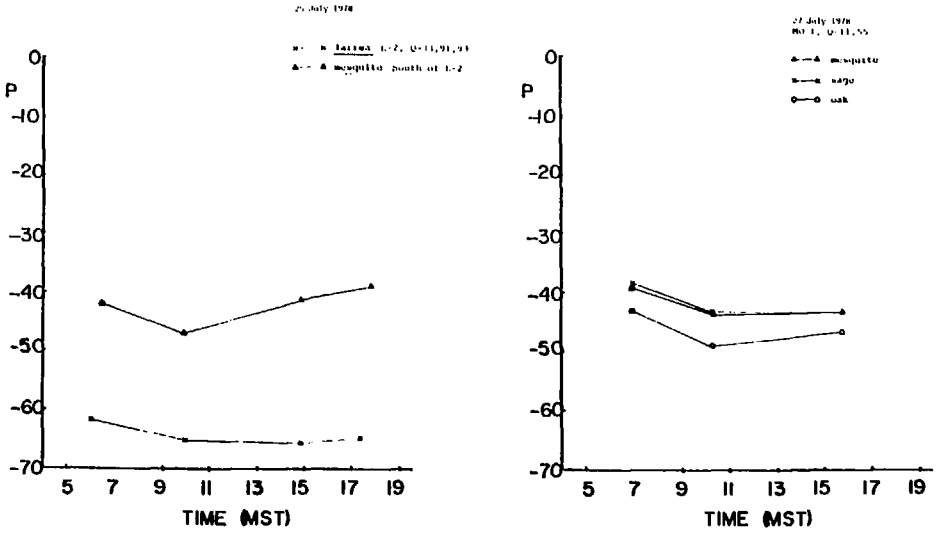

Figure 4.5. Xylem pressure potentials of shrubs from Study Sites L-2 and MO-1 25, 27 July 1978.

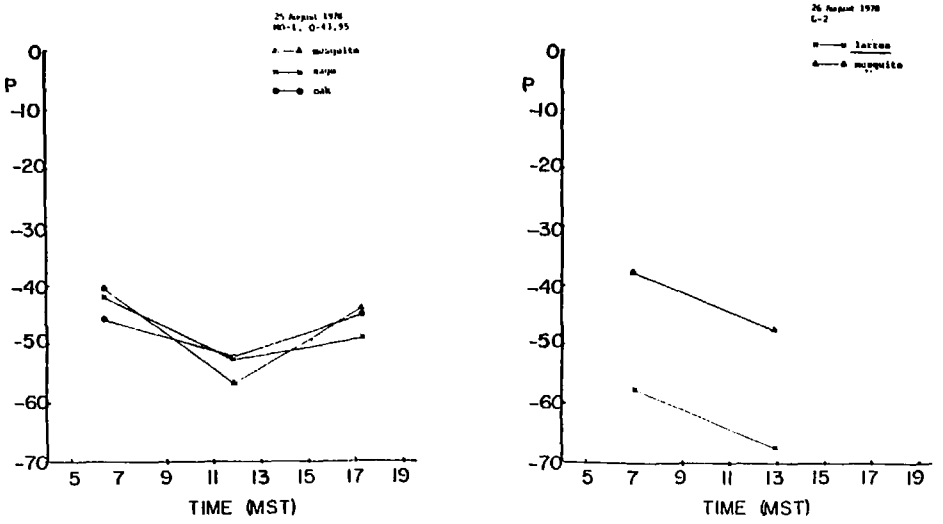

Figure 4.6. Xylem pressure potentials of shrubs from Study Sites MO-1 and L-2 25,26 August 1978.

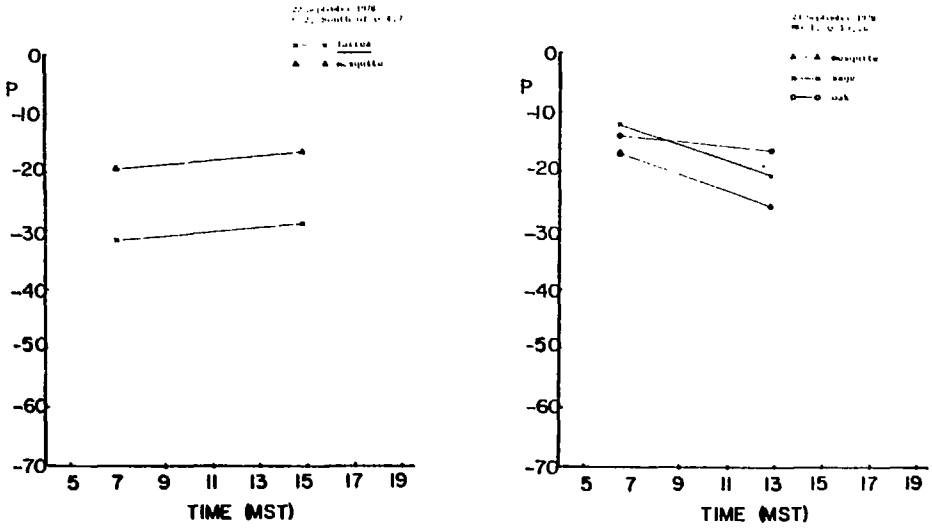

Figure 4.7. Xylem pressure potential of shrubs from Study Sites L-2 and MD-1 22, 23 September 1978.

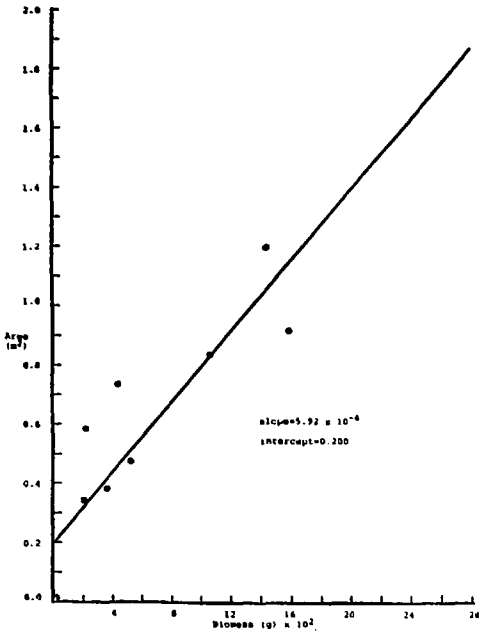

Figure 4.8. Relationship between canopy area and total biomass of Larrea tridentata.

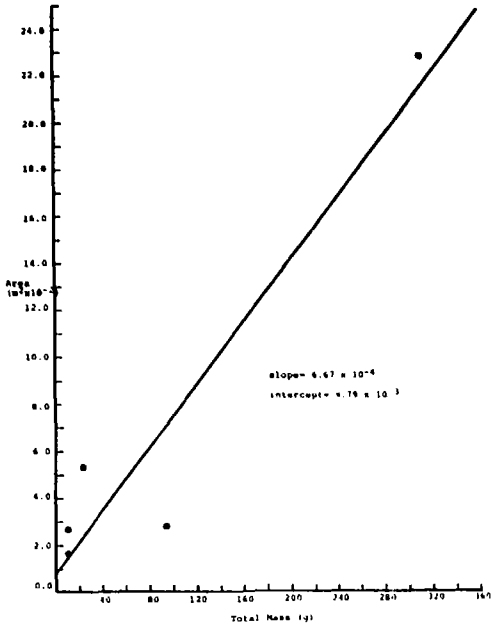

Figure 4.9. Relationship between canopy area and total biomass of Artemisia filifolia.

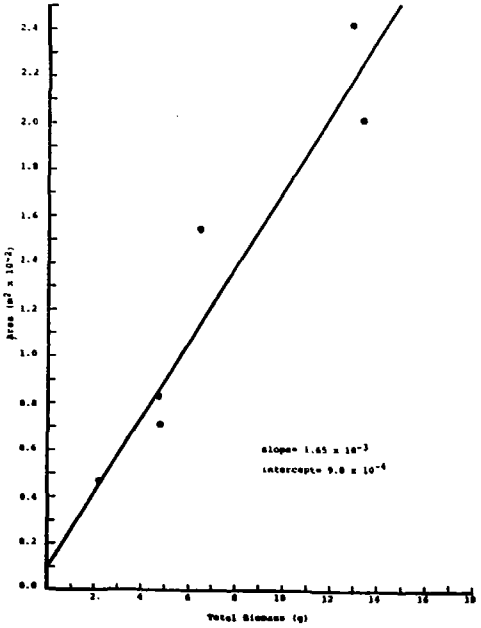

Figure 4.10. Relationship between canopy area and total biomass of Gutierrezia sarothrae.

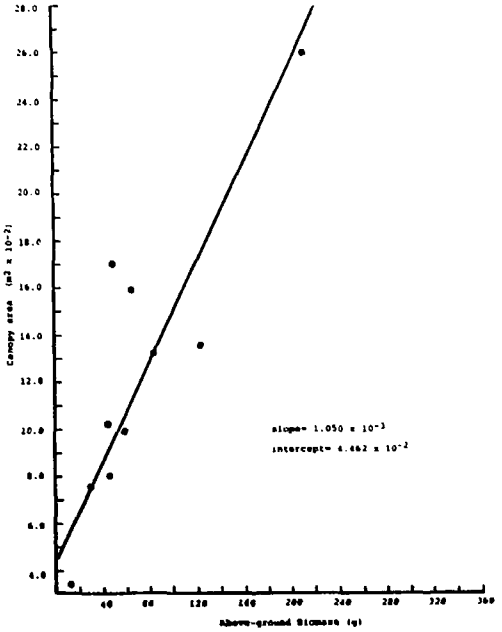

Figure 4.11. Relationship between canopy area and above-ground biomass of Quercus havardii.

Table 4.1. Mechanical analyses and textures of soils from the Los Medaños area.

Soil Series	Site	Depth cm	>2 mm %	Sand %	Silt %	Clay %	Texture
Berino complex	3	0-10	0.8	95.4	2.6	2.0	sand
		25-36	0.2	95.8	0.4	3.8	sand
	6	0-10	-	96.6	2.0	1.4	sand
		25-36	-	97.6	0.8	1.6	sand
	8	0-10	-	98.2	1.8	0	sand
		15-36	-	97.8	2.2	0	sand
	8A	0-10	-	98.4	1.4	0.2	sand
	under oak	25-36	-	97.6	1.6	0.8	sand
	8B	0-10	-	98.4	0.6	1.0	sand
	under mesquite	25-36	-	97.6	1.4	1.0	sand
	9	0-10	-	98.0	0.6	1.4	sand
		15-36	-	98.8	0.6	0.6	sand
	11	0-10	-	98.2	1.4	0.4	sand
		25-36	-	99.0	0.4	0.6	sand
	12	0-10	-	98.8	0.8	0.4	sand
		25-36	-	98.4	1.0	0.6	sand
	13	0-10	-	99.8	0.2	0	sand
		25-36	-	99.6	0.4	0	sand
	14	0-10	-	95.6	4.4	0	sand
		25-36	-	96.0	4.0	0	sand
Hermit	4	0-10	-	99.0	0.6	0.4	sand
		25-36	-	98.8	0.4	0.8	sand
	4A	0-10	-	99.6	0.4	0	sand
	under mesquite	25-36	-	99.8	0.2	0	sand
	7	0-10	-	99.2	0.6	0.2	sand
		25-36	-	98.6	0.8	0.6	sand
Pyote	2	0-10	-	96.4	1.8	1.8	sand
		25-36	-	94.6	3.2	2.2	sand
Pajarito	10	0-10	-	79.4	0.4	20.2	sandy clay loam
		25-36	-	81.8	7.0	11.2	sandy loam
	10A	0-10	-	80.4	16.0	3.6	loamy sand
	under mesquite	25-36	-	83.0	14.2	2.8	loamy sand
Wink	5	0-10	1.2	80.4	14.6	5.0	loamy sand
		25-36	2.8	72.4	16.0	11.6	sandy loam
Simona[a]	1	0-10	23.8	72.4	21.4	6.2	sandy loam
	1A	0-10	24.0	71.8	19.0	9.2	sandy loam
Simona-Nippus complex	15	0-10	19.7	75.6	18.0	6.4	sandy loam
		25-36	51.7	70.4	18.2	11.4	sandy loam

[a]Two adjacent open sites sampled.

Table 4.2. Water retention characteristics of soils from the Los Medaños area

Soil Series	Sample Site	Depth cm	Field Capacity %	Permanent Wilting Pt %	Net Available %
Berino complex	3	0-10	6.25	1.71	4.54
		25-36	7.15	2.17	4.98
	6	0-10	6.30	1.23	5.07
		25-36	3.55	0.87	2.68
	8	0-10	2.85	1.05	1.80
		25-36	2.70	0.95	1.75
	8A under oak	0-10	3.20	1.32	1.88
		25-36	2.85	1.39	1.46
	8B under mesquite	0-10	4.45	1.31	3.14
		25-36	5.15	1.43	3.72
	9	0-10	4.10	0.97	3.13
		25-36	2.55	2.20	0.35
	11	0-10	3.20	1.86	1.34
		25-36	2.75	1.78	0.97
	12	0-10	3.85	1.66	2.19
		25-36	4.90	2.01	2.89
	13	0-10	3.20	1.58	1.62
		25-36	2.90	1.91	0.99
	14	0-10	3.00	1.30	1.70
		25-36	4.25	3.05	1.20
Kermit	4	0-10	2.80	0.99	1.81
		25-36	5.15	0.55	4.60
	4A under mesquite	0-10	10.30	0.67	9.63
		25-36	8.55	2.47	6.08
	7	0-10	3.95	1.26	2.69
		25-36	2.65	1.49	1.16
Pyote	2	0-10	4.10	1.70	2.40
		25-36	8.35	1.89	6.46
Pajarito	10	0-10	11.10	5.57	5.53
		25-36	13.95	6.83	7.12
	10A under mesquite	0-10	7.60	4.22	3.38
		25-36	5.25	3.37	1.88
Wink	5	0-10	17.80	4.95	12.85
		25-36	20.90	4.62	16.28
Simona[a]	1	0-10	15.75	5.31	10.44
	1A	0-10	22.10	5.80	16.30
Simona-Bippus complex	15	0-10	15.60	5.70	9.90
		25-36	16.95	7.94	9.01

[a]Two adjacent open sites sampled.

Table 4.1. Organic matter and organic carbon, extractable phosphorus, total nitrogen, and carbon nitrogen ratio of soils from the Los Medinos area (air-dry) basis

Soil Series	Sample Site	Depth cm	Organic Matter %	Carbon %	Phosphorus µg/g	Total Nitrogen %	C/N
Berino complex	3	0-10	0.35	0.21	0	0.022	9.5
		25-36	0.20	0.15	0	0.020	7.5
	6	0-10	0.27	0.15	2.8	0.017	8.8
		25-36	0.17	0.10	0.1	0.012	8.3
	8	0-10	0.25	0.145	2.1	0.013	11.2
		25-36	0.16	0.09	0	0.011	8.2
	8A under oak	0-10	0.40	0.24	0	0.020	12.0
		25-36	0.28	0.16	0	0.015	10.7
	8B under mesquite	0-10	0.55	0.31	12.4	0.052	6.0
		25-36	0.335	0.195	3.5	0.022	8.9
	9	0-10	0.45	0.26	2.3	0.022	11.8
		25-36	0.20	0.12	.28	0.001	
	11	0-10	0.26	0.16	1.4	0.029	5.5
		25-36	0.18	0.105	0	0.019	5.5
	12	0-10	0.25	0.14	2.9	0.032	4.4
		25.36	0.17	0.10	1.3	0.020	5.0
	13	0-10	0.20	0.12	2.9	0.019	6.3
		25-36	0.13	0.075	0	0.016	4.7
	14	0-10	0.30	0.18	3.5	0.028	6.4
		25-36	0.21	0.12	0.1	0.020	6.0
Kermit	4	0-10	0.31	0.18	3.1	0.016	11.2
		25-36	0.13	0.08	0.1	0.011	7.3
	4A under mesquite	0-10	0.68	0.39	12.8	0.032	12.2
		25-36	0.45	0.26	8.5	0.019	13.7
	7	0-10	0.20	0.12	2.7	0.012	10.0
		25-36	0.18	0.10	0.5	0.009	11.1
Pyote	2	0-10	0.32	0.18	0	0.016	11.2
		25-36	0.22	0.13	0	0.018	7.2
Pajarito	10	0-10	0.20	0.11	4.4	0.020	5.5
		25-36	0.16	0.10	0	0.019	5.3
	10A under mesquite	0-10	0.61	0.35	6.8	0.065	5.4
		25-36	0.50	0.29	1.1	0.075	3.9
Wink	5	0-10	0.55	0.32	1.3	0.079	4.1
		25-36	0.61	0.36	0	0.041	8.8
Simona[a]	1	0-10	1.21	0.71	0.1	0.082	8.7
	1A	0-10	1.12	0.65	1.2	0.073	8.9
Simona-Nippus complex	15	0-10	0.645	0.34	8.5	0.058	5.9
		25-36	0.50	0.29	3.2	0.0003	

[a] Two adjacent open sites sampled.

Table 4.4. Some chemical characteristics of soils of the Los Medaños Area.

Soil Series	Sample Site	Depth cm	pH	Cation-Exchange Capacity[b] meq/100g	Electrical Conductivity mmhos/cm	Saturation Paste Extract: Sodium mg/l	Potassium mg/l	Calcium mg/l	Magnesium mg/l
Berino complex	3	0-10	6.94	3.53	0.32	6.0	15.3	16.5	4.2
		25-36	7.12	5.03	0.12	4.0	8.0	15.8	3.0
	6	0-10	8.02	3.00	0.16	3.4	6.8	30.3	3.7
		25-36	7.85	2.67	0.14	3.9	10.7	22.0	4.3
	8	0-10	7.53	2.50	0.115	3.5	11.0	17.0	5.0
		25-36	7.61	2.61	0.11	4.1	6.8	15.0	2.2
	8A under oak	0-10	7.62	2.68	0.10	1.6	10.7	14.8	3.0
		25-36	7.69	2.68	0.19	5.5	9.5	23.5	5.0
	8B under mesquite	0-10	6.05	2.68	0.50	2.1	28.5	67.7	11.5
		25-36	6.57	2.84	0.34	2.2	21.5	47.7	7.5
	9	0-10	7.61	3.10	0.185	2.6	9.0	29.0	5.8
		25-36	7.78	3.02	0.21	2.5	8.3	32.0	4.5
	11	0-10	7.43	2.69	0.14	2.6	8.3	20.3	3.8
		25-36	7.51	2.69	0.07	2.4	6.2	10.3	3.0
	12	0-10	7.61	2.86	0.03	6.2	9.0	33.5	5.3
		25-36	7.52	2.94	0.105	5.9	3.7	15.2	2.7
	13	0-10	7.14	2.59	0.20	6.7	8.8	25.0	4.8
		25-36	7.28	2.68	0.20	3.8	4.5	19.3	5.0
	14	0-10	7.65	3.69	0.22	5.8	7.7	35.0	4.0
		25-36	7.73	4.36	0.22	6.7	7.5	30.8	4.5
Kermit	4	0-10	7.88	2.52	0.15	4.1	8.8	25.5	3.0
		25-36	7.78	2.35	0.09	4.9	7.8	12.5	3.2
	4A under mesquite	0-10	6.20	2.84	0.69	8.0	44.0	98.2	11.2
		25-36	6.08	2.67	0.30	5.4	24.5	38.3	5.0
	7	0-10	7.95	2.34	0.19	3.9	6.8	33.0	2.8
		25-36	7.84	2.51	0.11	2.8	5.2	18.0	2.5
Pyote	2	0-10	7.63	3.00	0.17	5.9	22.0	21.2	4.5
		25-36	7.64	3.85	0.14	4.4	11.5	17.7	3.0
Pajarito	10	0-10	7.05	12.17	0.10	3.5	3.5	12.3	3.5
		25-36	6.96	13.27	0.10	4.2	2.5	12.5	3.3
	10A under mesquite	0-10	7.42	6.97	0.35	2.9	37.5	38.5	9.5
		25-36	7.87	5.56	0.41	3.2	30.5	55.5	9.8
Wink	5	0-10	7.80	6.21	0.27	2.9	6.5	42.0	9.2
		25-36	8.02	9.09	0.26	3.0	5.7	37.5	12.0
Simona[a]	1	0-10	7.59	11.78	0.38	4.0	12.0	80.0	5.5
	1A	0-10	7.87	13.11	0.35	4.3	10.5	73.3	5.0
Simona-Bippus complex	15	0-10	7.83	8.76	0.43	10.3	16.3	68.0	6.7
		25-36	7.70	11.05	0.17	9.5	7.5	60.8	6.3

[a] Two adjacent open sites sample.
[b] Air dry basis.

Table 4.5. Total soil nitrogen of samples from study areas. Soil nitrogen is expressed as a percentage of the oven-dry weight of the soil.

Vegetation	Depth, cm	7	20	25	28	33	40	56	63	65	67	$\bar{x}$ ± S.E.
SITE MO-1												
QUADRAT												
Mesquite	0-10	.041	.029	.037	.021	.045	.026	.059	.052	.080	.055	.045±.006[a]
	10-46	.023	.016	.016	.013	.022	.023	.018	.023	.026	.019	.020±.001bc
	46-70	.013	.015	.011	.011	.016	.014	.015	.010	.018	.013	.014±.001defg
	70-100				.008	.011					.012	.010±.001
Oak	0-10	.038	.010	.024	.016	.023	.031	.029	.020	.027	.019	.024±.003b
	10-46	.015	.011	.017	.014	.018	.047	.025	.013	.015	.012	.019±.003bcd
	46-70	.010	.009	.011	.017	.012	.025	.011	.010	.011	.011	.013±.002defg
	70-100				.009	.010					.009	.009±.0003
Open	0-10	.013	.008	.015	.011	.013	.013	.011	.014	.013	.012	.012±.001efg
	10-46	.016	.011	.019	.009	.014	.009	.023	.012	.012	.021	.015±.002cdef
	46-70	.009	.010	.010	.008	.010	.010	.012	.010	.010	.015	.010±.001fg
	70-100				.007	.008					.011	.009±.001
SITE MO-2												
QUADRAT		1	13	30	36	53	56	68	84	88	95	$\bar{x}$ ± S.E.
Mesquite	0-10	.030			.020						.039	.030±.006
	10-46	.016			.014						.0185	.016±.001
	46-70	.011			.009						.011	.010±.001
	70-100	.011			.009						.009	.010±.001
Oak	0-10	.018	.020	.016	.012	.021	.009	.018	.023	.023	.019	.018±.001bcde
	10-46	.015	.014	.012	.010	.011	.013	.009	.014	.015	.016	.013±.001defg
	46-70	.012	.004	.009	.009	.011	.008	.010	.008	.008	.014	.009±.001fg
	70-100	.010	.007	.009	.007	.007	.007	.016	.008	.007	.011	.009±.001fg
Open	0-10	.015	.017	.013	.012	.011	.008	.014	.014	.013	.014	.013±.001defg
	10-46	.011	.012	.011	.010	.007	.008	.011	.011	.010	.013	.010±.001fg
	46-70	.010	.009	.007	.009	.007	.007	.010	.009	.009	.010	.009±.000fg
	70-100	.011	.007	.006	.008	.009	.006	.009	.004	.007	.010	.008±.001g
Sage	0-10			.020			.016	.021	.019	.019	.020	.019±.001
	10-46			.012			.015	.015	.014	.012	.016	.014±.001
	46-70			.008			.012	.010	.010	.010	.017	.011±.001
	70-100			.006			.011	.009	.007	.007	.015	.009±.001
SITE L-1												
QUADRAT		10	38	49	51	53	59	81	84	89	98	$\bar{x}$ ± S.E.
Open	0-10	.065	.073	.059	.082	.094	.068	.072	.120	.060	.059	.075±.006abc
	10-25			.058	.041	.132	.079	.104	.123	.073	.073	.085±.011
	25-46			.073								.073±.000
Larrea	0-10	.070	.053	.057	.147	.078	.063	.063	.099	.083	.074	.079±.009abc
	10-25	.093	.069	.083	.046	.082		.089	.118	.068	.127	.086±.008
SITE L-2												
QUADRAT		1	2	13	29	34	35	57	67	76	83	$\bar{x}$ ± S.E.
Open	0-10	.062	.056	.062	.069	.076	.053	.064	.065	.075	.058	.064±.002c
	10-25	.096	.077	.087	.114	.091	.076	.066	.099	.093	.064	.086±.005a
Larrea	0-10	.056	.057	.064	.082	.055	.106	.082	.058	.073	.059	.069±.005bc
	10-25	.087	.071	.095	.095	.071	.085	.087	.080	.087	.077	.084±.003ab

[a]Within a plant community, means followed by a common letter do not differ significantly (P=0.05). Only means based on 10 replicate quadrats were tested statistically.

Table 4.6. Phosphorus extractable in 0.5 M $NaHCO_3$ from soil samples from the study area. Phosphorus is expressed as µg P/g oven-dry soil.

Vegetation	QUADRAT / Depth cm	7	20	25	28	33	40	56	63	65	67	[illegible]
						SITE MO-1						
Mesquite	0-10	3.2	3.5	2.8	2.7	1.6	3.3	9.3	11.1	4.5	8.7	[illegible]
	10-46	1.4	2.9	1.6	0.7	1.5	1.6	2.5	1.6	3.9	1.1	[illegible]
	46-70	0.5	1.3	1.5	0.8	1.0	2.1	2.6	0.9	2.2	0.5	[illegible]
	70-100				0.3	0.9					1.8	[illegible]
Oak	0-10	0.1	0.8	2.7	4.3	3.8	3.9	2.3	3.2	1.7	3.5	[illegible]
	10-46	1.2	0.7	0.5	0.6	1.7	2.2	1.2	0.8	1.9	1.1	[illegible]
	46-70	0.1	1.2	0.2	0.1	0.7	0.5	0.4	0.1	1.3	1.2	[illegible]
	70-100				0.2	1.6					2.5	[illegible]
Open	0-10	0.9	1.8	0.2	2.5	2.4	1.1	3.0	2.2	1.9	2.0	[illegible]
	10-46	0	0.5	0	0.5	1.6	0.7	1.3	1.6	0.9	0.8	[illegible]
	46-70	0.5	0.8	0.4	0.1	0.2	0.9	0.6	0.7	0.6	1.2	[illegible]
	70-100				1.3	0.8					2.4	[illegible]
						SITE L-1						
QUADRAT		10	38	49	51	53	59	81	84	89	88	[illegible]
Open	0-10	10.5	9.6	6.3	11.6	9.6	6.6	8.3	7.8	7.5	8.2	[illegible]
	10-25	--	--	3.7	7.9	6.1	3.9	4.7	3.7	7.4	7.0	[illegible]
	25-46			3.3								3.1
Larrea	0-10	7.7	6.9	4.6	8.9	12.2	7.7	3.3	2.6	5.4	4.5	[illegible]
	10-25	3.2	2.6	4.7	5.3	6.9	--	4.1	2.2	4.1	3.0	[illegible]
						SITE L-2						
QUADRAT		1	2	13	29	34	35	57	67	76	81	[illegible]
Open	0-10	6.5	6.4	8.0	6.8	6.5	5.6	5.6	6.2	5.0	5.4	[illegible]
	10-25	2.0	5.2	5.5	4.3	1.7	2.6	2.6	2.6	[illegible]	3.8	[illegible]
Larrea	0-10	3.2	8.4	10.0	6.8	3.6	24.5	6.4	4.6	5.2	4.8	[illegible]
	10-25	1.4	7.6	2.8	6.0	1.7	10.1	5.8	2.7	5.0	6.6	[illegible]

[a]Within a plant community, means followed by a common letter do not differ significantly (P=0.05). Only means based on 10 replicate quadrat s were tested statistically.

Table 4.7. Total soil organic matter of samples from study areas. Soil organic matter is expressed as a percentage of the oven-dry weight of the soil.

Vegetation	Depth cm	7	20	25	28	33	40	56	63	65	67	$\bar{x}$ ± S.E.	
SITE MO-1													
Mesquite	0-10	.822	.560	.735	.421	1.17	.502	1.09	1.02	1.53	.788	.864±.108	a a
	10-46	.514	.225	.320	.341	.366	.392	.590	.354	.454	.362	.392±.033	bc
	46-70	.489	.261	.261	.142	.337	.232	.215	.300	.194	.141	.257±.033	cd
	70-100				.098	.130					.203	.144±.031	
Oak	0-10	.493	.165	.485	.337	.477	1.02	.389	.353	.581	.274	.457±.073	b
	10-46	.312	.337	.337	.151	.303	.809	.291	.367	.241	.224	.337±.056	bc
	46-70	.232	.268	.268	.136	.198	.941	.211	.151	.190	.134	.273±.076	cd
	70-100				.064	.165					.113	.114±.029	
Open	0-10	.240	.169	.376	.198	.243	.261	.253	.236	.166	.219	.236±.019	cd
	10-46	.240	.151	.422	.126	.249	.211	.211	.200	.161	.292	.226±.027	cd
	46-70	.055	.169	.129	.118	.177	.206	.172	.165	.130	.224	.155±.015	d
	70-100				.104	.194		.147			.141	.147±.018	
SITE L-1													
QUADRAT		10	38	49	51	53	59	81	84	89	98	$\bar{x}$ ± S.E.	
Open	0-10	1.06	1.04	.881	1.40	1.49	.974	1.18	1.89	.907	1.03	1.19 ±.10	ab
	10-25			.965	1.67	1.78	1.22	1.52	1.98	.937	1.18	1.41 ±.14	
	25-46			.870								.870±.000	
Larrea	0-10	1.48	.960	1.06	1.52	1.13	.985	1.18	1.55	.767	1.24	1.19 ±.08	ab
	10-25	1.36	1.21	.801	1.72	1.55		1.44	1.79	1.22	1.32	1.38 ±.10	
SITE L-2													
QUADRAT		1	2	13	29	34	35	57	67	76	83	$\bar{x}$ ± S.E.	
Open	0-10	1.06	.929	1.01	.910	1.07	.889	.959	.974	1.12	.977	.99±.02	b
	10-25	1.44	1.35	1.34	1.72	1.41	1.19	1.37	1.52	1.43	1.26	1.40±.05	a
Larrea	0-10	.962	.835	.892	1.45	.989	1.29	1.47	1.08	1.11	.787	1.09±.08	b
	10-25	1.40	1.14	1.40	1.65	1.14	1.83	1.45	1.02	1.36	1.08	1.35±.08	a

[a] Within a plant community, means followed by a common letter do not differ significantly (P=0.05). Only means based on 10 replicate quadrats were tested statistically.

Table 4.8. Organic carbon content of soil samples from study areas. Organic carbon is expressed as a percentage of the oven-dry weight of the soil.

Vegetation	Depth cm	7	20	25	28	33	40	56	63	65	67	$\bar{x}$ ± S.E.
						SITE MO-1						
QUADRAT												
Mesquite	0-10	.478	.326	.427	.215	.680	.292	.634	.593	.890	.458	.502±.063 a[a]
	10-46	.300	.131	.186	.198	.213	.228	.343	.206	.264	.210	.228±.019 bc
	46-70	.284	.152	.152	.083	.196	.135	.125	.174	.113	.082	.150±.019 cd
	70-100	--	--	--	.057	.076	--	--	--	--	.118	.084±.018
Oak	0-10	.287	.096	.282	.196	.277	.593	.226	.205	.338	.159	.266±.043 b
	10-46	.181	.196	.196	.088	.176	.470	.169	.213	.140	.130	.156±.034 bc
	46-70	.135	.156	.156	.079	.115	.135	.123	.083	.110	.078	.117±.092 cd
	70-100	--	--	--	.037	.096	--	--	--	--	.066	.066±.021
Open	0-10	.140	.098	.219	.115	.141	.151	.147	.137	.097	.127	.137±.011 cd
	10-46	.140	.088	.245	.073	.145	.123	.123	.116	.094	.170	.132±.015 cd
	46-70	.032	.098	.075	.069	.103	.120	.100	.096	.076	.130	.090±.009 d
	70-100	--	--	--	.061	.113	--	.086	--	--	.082	.085±.011
						SITE L-1						
QUADRAT		10	38	49	51	53	59	81	84	89	98	$\bar{x}$ ± S.E.
Open	0-10	.616	.605	.513	.817	.870	.567	.685	1.10	.528	.598	.690±.059 ab
	10-25	--	--	.562	.971	1.04	.711	.882	1.16	.545	.686	.820±.081
	25-46	--	--		--	--	--	--	--	--	--	
Larrea	0-10	.860	.558	.617	.881	.658	.573	.687	.899	.446	.723	.690±.048 ab
	10-25	.791	.703	.465	1.00	.900	--	.836	1.04	.712	.765	.801±.058
						SITE L-2						
Open	0-10	.616	.540	.587	.529	.623	.517	.557	.566	.653	.568	.576±.014 b
	10-25	.837	.785	.790	1.02	.832	.700	.808	.897	.844	.742	.826±.028 a
Larrea	0-10	.559	.485	.519	.845	.575	.751	.857	.628	.646	.458	.632±.045 b
	10-25	.814	.663	.811	.958	.664	1.06	.841	.594	.788	.629	.782±.047 a

[a] Within a plant community, means followed by a common letter do not differ significantly (P=0.05). Only means based on 10 replicate quadrats were tested statistically.

Table 4.9. Saturation paste pH values of soil samples from MO-1 and L-1 study areas.

QUADRAT / Vegetation	Depth cm	7	20	25	28	33	40	56	63	65	67	$\bar{x}$ ± S.E.
						SITE MO-1						
Mesquite	0-10	6.33	6.38	5.99	7.06	5.27	6.47	6.21	5.33	6.15	5.80	6.09±.18 d[a]
	10-46	7.30	7.35	7.52	7.29	6.84	7.55	6.92	6.55	6.85	6.70	7.06±.12 abc
	46-70	7.07	7.13	7.76	7.27	7.34	7.55	7.52	6.70	7.77	7.52	7.36±.10 ab
	70-100				7.48	7.32					7.39	7.42±.03
Oak	0-10	7.01	7.05	6.47	6.70	6.80	7.84	6.70	6.74	6.41	6.60	6.83±.13 c
	10-46	7.42	7.50	7.26	7.21	7.21	8.08	7.42	7.32	7.25	7.12	7.38±.09 ab
	46-70	7.49	7.15	7.40	7.43	7.50	8.25	7.40	7.24	7.42	6.92	7.41±.11 a
	70-100				7.56	7.60					6.93	7.38±.23
Open	0-10	7.02	6.90	7.30	7.35	6.80	7.05	6.87	6.92	6.98	7.04	7.02±.06 bc
	10-46	7.36	7.12	8.03	7.33	7.14	6.97	7.10	7.41	7.22	8.10	7.38±.12 ab
	46-70	7.12	7.05	8.00	7.26	7.22	6.95	7.00	7.25	7.15	7.96	7.29±.12 ab
	70-100				7.29	7.39					7.85	7.52±.17
						SITE L-1						
QUADRAT		10	38	51	49	53	59	81	84	89	98	$\bar{x}$ ± S.E.
Larrea	0-10	8.17	8.28	8.09	8.47	7.85	8.15	8.21	8.14	8.28	8.15	8.18±.05 a
	10-25	8.18	8.40	8.26	8.42	8.09		8.28	8.23	8.41	8.01	8.25±.05
Open	0-10	8.25	8.30	8.25	8.24	8.25	8.25	8.18	8.16	8.35	8.23	8.25±.02 a
	10-25			8.39	8.20	8.20	8.28	8.23	8.24	8.20	8.19	8.24±.02

[a]Within a plant community, means followed by a common letter do not differ significantly (P=0.05). Only means based on 10 replicate quadrats were tested statistically.

Table 4.10. Summary of mean values for soil organic matter, carbon, total nitrogen, carbon nitrogen ratio and $NaHCO_3$ extractable phosphorus for study sites MO-1, L-1, and L-2.

	Depth	O.M.	C	Total N	C/N	P
	cm	%	%	%		µg/g
			SITE MO-1			
Mesquite	0-10	.864 ± .108[a]	.502	.045 ± .006	11.2	5.1 ± 1.1
	10-46	.392 ± .033	.228	.020 ± .001	11.4	1.1 ± 0.1
	46-70	.257 ± .033	.150	.014 ± .001	10.7	1.1 ± 0.2
	70-100	.144 ± .031	.084	.010 ± .001	8.4	1.0 ± 0.4
Oak	0-10	.457 ± .073	.266	.024 ± .003	11.1	2.5 ± 0.4
	10-46	.337 ± .056	.196	.019 ± .003	10.3	1.1 ± 0.2
	46-70	.273 ± .076	.117	.013 ± .002	9.0	0.6 ± 0.2
	70-100	.114 ± .029	.006	.009 ± .000	.7	1.5 ± 0.8
Open	0-10	.236 ± .019	.137	.012 ± .001	11.4	1.8 ± 0.3
	10-46	.226 ± .027	.132	.015 ± .002	8.8	0.8 ± 0.2
	46-70	.155 ± .015	.090	.010 ± .001	17.6	0.6 ± 0.1
	70-100	.147 ± .018	.085	.009 ± .001	9.4	1.5 ± 0.5
			SITE L-1			
Open	0-10	1.19 ± .10	.69	.075 ± .006	9.2	8.6 ± 0.5
	10-25	1.41 ± .14	.82	.085 ± .011	9.6	5.6 ± 0.6
	25-46	.87 ± .00	.51	.073 ± .000	7.0	3.3 ± 0.0
Larrea	0-10	1.19 ± .08	.69	.079 ± .009	8.7	6.7 ± 0.9
	10-25	1.38 ± .10	.80	.086 ± .008	9.3	4.0 ± 0.5
			SITE L-2			
Open	0-10	.99 ± .02	.57	.064 ± .002	8.9	6.0 ± 0.3
	10-25	1.40 ± .05	.83	.086 ± .005	9.7	3.2 ± 0.4
Larrea	0-10	1.09 ± .08	.63	.069 ± .005	9.1	7.2 ± 2.0
	10-25	1.35 ± .08	.78	.084 ± .003	9.3	4.6 ± 0.7

[a]Standard error

TABLE 4.11. Saturation paste pH values of composite soil samples from study areas.

SITE Vegetation	Depth cm	MO-1	MO-2
Mesquite	0-10	6.00	6.90
	10-46	7.21	7.45
	46-70	7.50	7.55
	70-100	7.65	7.42
Oak	0-10	7.05	6.95
	10-46	7.55	7.50
	46-70	7.60	7.51
	70-100	7.49	7.50
Open	0-10	6.96	7.20
	10-46	7.60	7.39
	46-70	7.45	7.35
	70-100	7.61	7.20
Sage	0-10		7.20
	10-46		7.69
	46-70		7.28
	70-100		7.60
SITE		L-1	L-2
Larrea	0-10	8.20	8.01
	10-25	8.25	8.10
Open	0-10	8.20	8.25
	10-25	8.24	8.32

Table 4.12. Mechanical analyses and textures of composite soil samples from study sites.

Study site	Vegetation type	Depth cm	>2 mm %	Sand %	Silt %	Clay	Texture	No. Samples[a]
MO-1	Mesquite	0-10		95.5	2.0	2.5	sand	10
		10-46		94.6	2.5	2.8	sand	10
		46-70		94.3	2.4	3.4	sand	10
		70-100		93.4	2.9	3.7	sand	3
	Oak	0-10		95.8	1.7	2.4	sand	10
		10-46		96.1	.9	3.0	sand	10
		46-70		95.6	1.0	3.4	sand	10
		70-100		93.8	2.2	4.0	sand	3
	Open	0-10		94.6	3.1	2.3	sand	10
		10-46		96.0	1.9	2.2	sand	10
		46-70		95.4	2.0	2.6	sand	10
		70-100		93.0	2.9	4.2	sand	10
MO-2	Mesquite	0-10		93.0	3.9	3.0	sand	3
		10-46		93.6	3.4	3.0	sand	3
		46-70		93.4	3.4	3.3	sand	3
		70-100		93.4	2.2	4.5	sand	3
	Oak	0-10		94.4	2.4	3.2	sand	10
		10-46		94.4	2.3	3.3	sand	10
		46-70		93.3	4.0	2.7	sand	10
		70-100		94.1	3.2	2.7	sand	10
	Open	0-10		94.0	3.0	3.0	sand	10
		10-46		94.4	2.2	3.5	sand	10
		46-70		93.8	2.0	4.2	sand	10
		70-100		92.6	2.8	4.6	sand	10
	Sage	0-10		95.4	1.8	2.8	sand	6
		10-46		94.4	2.4	3.2	sand	6
		46-70		94.4	2.4	3.2	sand	6
		70-100		93.2	3.4	3.4	sand	6
L-1	Larrea	0-10	12.2	79.1	14.2	6.8	loamy sand	10
		10-25	36.5	77.8	14.0	8.3	sandy loam	9
	Open	0-10	34.7	75.4	15.1	9.5	sandy loam	10
		10-25	50.3	72.6	16.8	10.6	sandy loam	8
		25-46	23.7	71.2	18.1	10.8	sandy loam	1
L-2	Larrea	0-10	12.5	78.9	15.8	5.3	loamy sand	10
		10-25	39.0	75.7	18.7	5.6	sandy loam	10
	Open	0-10	31.1	76.5	18.1	5.4	loamy sand	10
		10-25	64.2	77.8	16.0	6.3	loamy sand	10

[a]Number of samples (quadrats) combined in composite sample.

Table 4.13. Water retention characteristics of composite soil samples from study sites.

Study site	Vegetation type	Depth cm	Field capacity %	Permanent wilting point %	Net available %
MO-1	Mesquite	0-10	8.42	2.15	6.27
		10-46	5.69	1.56	4.13
		46-70	4.96	2.30	2.66
		70-100	7.43	1.19	6.24
	Oak	0-10	7.89	1.99	5.90
		10-46	7.18	2.60	4.58
		46-70	7.61	1.54	6.07
		70-100	7.88	1.65	6.23
	Open	0-10	3.63	2.28	1.35
		10-46	4.69	1.83	2.86
		46-70	6.33	2.07	4.26
		70-100	7.72	.89	6.83
L-1	*Larrea*	0-10	15.49	3.07	12.42
		10-25	17.97	4.62	13.35
	Open	0-10	11.07	6.12	4.95
		10-25	18.64	5.06	13.58
		25-46	14.60	6.29	8.31
L-2	*Larrea*	0-10	10.27	4.05	6.22
		10-25	12.03	4.54	7.49
	Open	0-10	9.73	4.31	5.42
		10-25	17.90	4.10	13.80

Table 4.14. Some characteristics of soil crusts from the *Larrea* study site (air-dry basis).

	Depth cm	Organic Matter %	Carbon %	Nitrogen %	C/N
Algal Crust A					
surface	0-0.3	2.30	1.34	0.142	9.4
subsurface	0.3-2.5	0.700	0.407	0.049	8.3
Algal Crust B					
surface	0-0.3	2.56	1.49	0.174	8.6
subsurface	0.3-2.5	1.70	0.988	0.060	16.5

Table 4.15. Water content of soil samples collected at the mesquite-oak study site (MO-1) expressed as percentage of oven-dry weight. Values are means for two quadrats sampled.

Date		17 May 1978	1 Jun 1978	15 Jun 1978	12 Jul 1978	27 Jul 1978	9 Aug 1978	25 Aug 1978	23 Sep 1978
Vegetation	Depth cm								
Mesquite	0-10	.51	.66	2.51	.54	1.43	.84	.33	6.41
	10-25	1.79	1.07	3.65	.75	.54	.96	.47	6.84
	25-46	1.34	1.01	2.77	.89	.83	.56	.63	5.88
	46-70	.86	1.25	1.76	.90	1.20	.91	.80	1.22
	70-100	.89	1.41	2.55	1.00	2.94	.93	1.24	1.14
	100-127	1.65	2.48	3.86	3.50				
Oak	0-10	.32	.54	1.74	.50	1.42	.68	.63	5.79
	10-25	.84	1.53	3.22	.58	.95	.87	.61	6.31
	25-46	.81	1.17	1.36	.90	.79	.84	.78	6.07
	46-70	1.01	1.41	1.18	.98	1.09	1.00	.73	1.05
	70-100	1.84	2.68	1.19	.97	1.34	1.65	1.08	1.27
	100-127	2.13	3.51	2.20	1.32				
Sage	0-10		.68	1.48	.34	2.15	.68	.50	5.99
	10-25		1.19	3.23	.85	.50	.57	.48	7.01
	25-46		1.24	2.33	.87	.68	.64	.72	6.72
	46-70		1.25	1.36	1.02	1.09	1.01	.86	2.23
	70-100		2.08	1.29	1.78	1.27	1.07	.89	1.07
	100-127		1.50	3.75	1.60				
Open	0-10	.64	.54[1]		.28	2.01	.73	.68	4.68
	10-25	.77	2.62		.65	.95	.67	.50	6.54
	25-46	.72	.81		1.33	.91	.98	.80	6.74
	46-70	.99	1.57		1.08	1.24	.93	.79	1.22
	70-100	.98	3.87		1.09	1.88	1.56	1.16	2.53
	100-127	2.99	4.20		2.27				

[a]Means for three quadrats samples on 17 May 1978 only.

Figure 4.16. Water content of soil samples collected at the *Larrea* study sites expressed as percentage of oven-dry weight. Values are means for three quadrats sampled.

Date Site Vegetation	Depth cm	2 Jun 1978 L-1	16 Jun 1978 L-1	13 Jul 1978 L-1	25 Jul 1978 L-2	26 Aug 1978 L-2	22 Sep 1978 L-2
Larrea	0-10	.94	2.81	1.10	1.71	1.72	12.08
	10-25	1.66	4.34	2.95	2.77	2.20	13.69
Open	0-10	1.97	2.77	1.54	2.39	1.43	14.77
	10-25		5.04	2.22	2.44	2.28	15.46
	25-46		3.52				
Mesquite	0-10				2.83	2.68	16.03
	10-25				2.66	3.07	11.67
	25-46						5.27

Table 4.17. Diffusive resistance of oak leaves at the MO-1 Study Site. Value for each quadrat are means of usually three determinations on each of three leaves from a clone.

Date	Quadrat	Time (MDT)	r_l (sec cm^{-1})	Leaf Temperature (°C)
15 June 1978	54	0545	18.4	23.7
	56		14.7	22.7
	$\bar{X}$		16.6	23 2
	54	1530	27.1	47.3
	56		28.6	46 0
	$\bar{X}$		27.9	46.7
12 July 1978	26	0630	24.3	24.6
	40		27.8	29.0
	$\bar{X}$		26.1	26.8
	26	1230	22.1	46.9
	40		18.0	47.8
	$\bar{X}$		20.1	47.4
	26	1730	23.7	45.0
	40		24.9	45.9
	$\bar{X}$		24.3	45.5
27 July 1978	11	0750	17.7	26.3
	55		21.0	27.2
	$\bar{X}$		19.4	26.8
	11	1130	24.8	42.0
	55		20.1	40.6
	$\bar{X}$		22.5	41.3
	11	1720	22.4	38.7
	55		27.1	38.2
	$\bar{X}$		24.8	38.5
9 Aug 1978	26	0700	13.4	18.2
	93		13.7	17.7
	$\bar{X}$		13.6	18.0
25 Aug 1978	43	0745	26.6	22.1
	95		27.2	29.2
	$\bar{X}$		26.9	25.7
	43	1330	23.8	40.5
	95		27.6	44.1
	$\bar{X}$		25.7	42.3
	43	1900	--	26.9
	95		--	26.1
	$\bar{X}$			26.5
22 Sept 1978	26	0815	27.1	18.4
	19		23.7	15.2
	$\bar{X}$		25.4	16.8
	26	1415	20.3	6.1
	19		20.3	4.3
	$\bar{X}$		20.3	5.2

Table 4.18. Line-intercept results for L-1 site.

Stratification	Species	% cover	Rel. cover
Shrub	*Larrea tridentata*	9.50	42.6
	Prosopis glandulosa	0.39	2.0
	Condalia sp.	0.26	0.2
		10.15	45.3
Half-shrub	*Gutierrezia sarothrae*	7.50	33.6
		7.50	33.6
Grass	*Muhlenbergia porteri*	4.19	18.8
	Sporobolus sp.	0.42	1.9
	Tridens pulchellus	0.07	0.3
		4.68	21.0
Total		22.33	99.9

Table 4.19. Line-intercept results for L-2 site.

Stratification	Species	% cover	Rel. cover
Shrub	*Larrea tridentata*	9.58	33.5
	Condalia sp.	1.31	4.6
		10.80	38.1
Half-shrub	*Gutierrezia sarothrae*	8.76	30.7
	Krameria lanceolata	5.85	20.5
		14.61	51.2
Forb	*Euphorbia* sp.	0.05	0.2
	other	0.16	0.6
		0.21	0.8
Grass	*Muhlenbergia porteri*	2.50	8.7
	Sporobolus sp.	0.28	1.0
	Tridens pulchellus	0.09	0.3
		2.87	10.0
Total		28.58	100.1

Table 4.20. Line-intercept results for MO-1 site

Stratification	Species	% Cover	Rel. cover
Shrub	*Prosopis glandulosa*	7.09	25.1
	Quercus havardii	6.90	24.4
	Artemisia filifolia	3.69	13.1
		17.68	62.6
Half-shrub	*Yucca elata*	2.70	9.5
	Croton sp.	3.08	10.9
		5.78	20.4
Forb	*Dithyrea wislezenii*	0.07	0.3
	other	0.01	0.0
		0.08	0.3
Grass	*Sporobolus* sp.	2.52	8.9
	Tridens pulchellus	0.21	0.7
	Setaria sp.	0.21	0.7
	Aristida sp.	1.19	4.2
	Muhlenbergia porteri	0.38	1.3
	others	0.19	0.6
		4.70	16.4
Total		28.24	99.7

Table 4.21. Line-intercept results for MO-2 site

Stratification	Species	% cover	Rel. cover
Shrub	*Prosopis glandulosa*	3.25	17.1
	Quercus havardii	8.03	42.2
	Artemisia filifolia	0.50	2.6
		11.78	61.9
Half-shrub	*Yucca elata*	1.28	6.7
	Croton sp.	0.69	3.6
	Chrysothamnus sp.	0.11	0.6
		2.08	10.9
Forb	*Euphorbia* sp.	0.20	1.1
	Heliotropium convolvulaceum	0.12	0.6
	others	0.06	0.3
		0.38	2.0
Grass	*Sporobolus* sp.	1.05	5.5
	Tridens pulchellus	0.31	1.7
	Aristida sp.	2.32	12.2
	Muhlenbergia porteri	0.49	2.6
	Bouteloua eriopoda	0.08	0.4
	Koeleria cristata	0.15	0.8
	others	0.38	1.9
		4.78	25.1
Total		19.02	99.9

Table 4.22. Average calculated plant component biomass ratios based on specimens collected at different sample sites.

Taxa (site)	Sample Size (n)	Biomass Ratios: live shoot:total ($\bar{y}$/S.E.)	root:total ($\bar{y}$/S.E.)	root:live shoot ($\bar{y}$/S.E.)	dead:total ($\bar{y}$/S.E.)
Larrea (L-1)	10	0.636 0.040	0.267 0.042	0.371 0.034	0.107 0.023
		shoot:total ($\bar{y}$/S.E.)	root:total ($\bar{y}$/S.E.)	root:shoot ($\bar{y}$/S.E.)	
Gutierrezia (L-1)	6	0.839 0.010	0.161 0.010	0.193 0.011	
Artemisia (MO-1)	5	0.591 0.010	0.409 0.010	0.694 0.027	

Table 4.23. Calculated slope, intercept, and biomass equations for the important taxa found on study sites.

Taxon	Sample Size	Slope	Intercept	Derived biomass-canopy area equation	Overestimation of biomass (g/m^2 of sampled specimens)	Correlation coefficient[e]
Larrea	9[b]	$5.92 \cdot 10^{-4}$	$2.09 \cdot 10^{-1}$	B=(A-0.209)x1573	38.1	.887
Gutierrezia	6	$1.65 \cdot 10^{-3}$	$9.00 \cdot 10^{-4}$	B=(A-0.0009)x606	1.3	.967
Artemisia	5	$6.67 \cdot 10^{-4}$	$9.79 \cdot 10^{-3}$	B=(A-0.0098)x1458	1.4	--
Quercus[c]	10	$1.05 \cdot 10^{-3}$	$4.46 \cdot 10^{-2}$	B=(A-0.045)913	13.6	.872
Condalia	5	$3.34 \cdot 10^{-4}$	$7.38 \cdot 10^{-2}$	B=(A-0.074)x2882	21.3	.988
Krameria	5	$6.39 \cdot 10^{-4}$	$4.41 \cdot 10^{-2}$	B=(A-0.044)x1510	19.1	.983
Yucca	4	$3.48 \cdot 10^{-4}$	$-2.51 \cdot 10^{-2}$	B=(A+0.025)x3709	150.4	.749
Opuntia[d]	12	4.06	66.5	B=(A-66.5)x0.246	0.0081 (g/cm^2)	.974
Croton	6	$3.03 \cdot 10^{-3}$	$8.11 \cdot 10^{-3}$	B=(A-0.0081)x226	0.3	.947
Euphorbia	3	$2.67 \cdot 10^{-2}$	$-5.39 \cdot 10^{-3}$	B=(A+0.0050)x38	-0.4	.992
Heliotropium	6	$1.14 \cdot 10^{-2}$	$-2.80 \cdot 10^{-3}$	B=(A+0.0028)x87	0.2	.996
Aristida	6	$5.65 \cdot 10^{-4}$	$4.81 \cdot 10^{-3}$	B=(A-0.0048)x1711	9.4	.922
Sporobolus	6	$9.03 \cdot 10^{-4}$	$-2.30 \cdot 10^{-3}$	B=(A+0.0023)x1118	2.2	.875
Muhlenbergia	6	$6.23 \cdot 10^{-4}$	$5.18 \cdot 10^{-3}$	B=(A-0.0052)x1542	6.2	.860
Panicum	6	$4.54 \cdot 10^{-4}$	$3.38 \cdot 10^{-3}$	B=(A-0.0034)x2088	39.3	.754
Tridens	6	$1.17 \cdot 10^{-2}$	$-3.10 \cdot 10^{-3}$	B=(A+0.0031)x86	-3.6	.496

[a]As determined by using the average of the largest and smallest diameter.

[b]One Larrea specimen was an apparent outlier and was consequently left out of the calculations.

[c]Only above-ground biomass is calculated.

[d]Calculated values refer to biomass per pad. Dimensions are in cm.

[e]Correlation coefficient (r^2) based on measured biomass and canopy area.

Table 4.24. Estimation of total biomass of plant taxa occurring on L-1 site using calculated biomass-canopy equations.

Taxa[a]	Total canopy cover (m^2/ha)	Estimated total biomass (kg/ha)
Larrea	950	1,494.3
Condalia	26	74.9
Gutierrezia	750	450.0
Muhlenbergia	419	646.1
Sporobolus	42	47.0
Tridens	7	0.6

[a]Prosopis is left out of calculations due to the lack of biomass data. Canopy area is 39 m^2/ha.

Opuntia present on site but not encountered in transect. Assume cover <0.1% or total cover of <10 m^2/ha.

Table 4.25. Estimation of total biomass of plant taxa occurring on L-2 site using calculated biomass-canopy equations.

Taxa	Total canopy cover (m^2/ha)	Estimated total biomass (kg/ha)
Larrea	958	1506.9
Condalia	131	377.5
Gutierrezia	876	525.6
Krameria	585	883.4
Euphorbia	5	0.2
Muhlenbergia	250	385.5
Sporobolus	28	31.3
Tridens	9	0.8

Table 4.26. Estimation of total biomass of plant taxa occurring on MO-1 site using calculated biomass-canopy equations.

Taxa[a]	Total canopy cover (m^2/ha)	Estimated total biomass (kg/ha)
Quercus[b]	690	6,929.7
Artemisia	369	538.0
Yucca[c]	270	866.4
Croton	308	69.6
Muhlenbergia	38	58.6
Sporobolus	252	281.7
Tridens	21	1.8
Aristida	119	203.6

[a]Prosopis is left out of calculations due to the lack of biomass data. Canopy area is 709 m^2/ha.

[b]Total Quercus biomass estimated using a 10:1 root to shoot ratio.

[c]Above-ground biomass only.

Table 4.27. Estimation of total biomass of plant taxa occurring on MO-2 site using calculated biomass-canopy equations.

Taxa[a]	Total canopy cover (m^2/ha)	Estimated total biomass (kg/ha)
Quercus[b]	803	8,064.5
Artemisia	50	72.9
Yucca[c]	128	410.8
Croton	69	15.6
Euphorbia	20	0.8
Heliotropium	12	1.0
Muhlenbergia	49	75.6
Sporobolus	105	117.4
Tridens	31	2.7
Aristida	232	397.0

[a]Prosopis is left out of calculations due to the lack of biomass data. Canopy area is 325 m^2/ha.

[b]Total Quercus biomass estimated using a 10:1 root to shoot ratio.

[c]Above-ground biomass only.

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CHAPTER 5

PRIMARY PRODUCTION PATTERNS ON THE LOS MEDAÑOS WIPP STUDY AREA FOR 1978

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Introduction

Primary productivity and standing-crop plant biomass form the base trophic level for an ecosystem study. The rate at which energy and nutrients are fixed and accumulated by plants provides a measure of the potential flow of energy and cycling of nutrients through ecosystems.[1] Consumers utilize the available plant energy and nutrients for their own growth. Some consumers, such as livestock, may leave the ecosystem and thus represent a flow of material out of the system. However, most of the energy and nutrients fixed by plants are utilized within the ecosystem and are turned over through death and decomposition on site. This report examines the rate of productivity and biomass accumulation by the major plant species in the Los Medaños WIPP study area. The data presented here will provide a measure of the energy available to consumers of the system and a potential amount of energy available for turnover by the decomposers of the system.

Study Area

For the purposes of this productivity study, the WIPP study area has been divided into three major vegetation zones: (1) the creosotebush-plain zone, (2) the vegetated-dune zone, and (3) the mesquite grassland-mesa zone (Fig. 5.1). The most intensive productivity measurements were

made in the large, central vegetated dune zone. This zone varies from higher dunes dominated by mesquite and sand sage to lower dunes dominated by shinnery oak, sage, and mesquite. The higher dune area corresponds to the "hummock-mesquite area" described by Best and Neuhauser in Chapter 1, while the lower dune area corresponds to their "oak-mesquite area." Limited productivity sampling was done in the creosotebush-plain zone in the southwest corner of the study area [the "creosotebush area," (Chap 1)] and in the mesquite grassland-mesa zone in the northeast corner of the study area [the "mesa" (Chap 1)]. The largely unvegetated high dunes east of James Ranch and minor vegetation types of the study area were not sampled.

Methods

The primary productivity of the vegetated sand dune zone was measured by monitoring the growth patterns of shinnery oak (Quercus havardii Rydb.), mesquite (Prosopis glandulosa Torr.), sand sage (Artemisia filifolia Torr.), snakeweed [Gutierrezia sarothrae (Pursh) Shinners], perennial grasses, annual grasses, perennial forbs, and annual forbs. The primary productivity of the mesquite grassland-mesa zone was measured by following the growth patterns of mesquite, burrograss (Scleropogon brevifolius Phil.), and black-grama [Bouteloua eriopoda (Torr.) Torr.]. The primary productivity of the creosotebush-plain zone was monitored by following the growth patterns of creosotebush [Larrea tridentata (DC) Cov.], burrograss, and snakeweed. Details of the sampling design and methods of monitoring the growth patterns of each of these species or life forms are given in Chapter 5 of the Ludwig and Freas annual report on biological investigations at the WIPP site.[2]

Results and Discussion

The mean standing-crop biomasses for the major shrubs occurring in the vegetated sand-dune zone at two different times during the growing season are given in Table 5.1. The biomass estimates in terms of per unit

area (hectare) for each shrub species are calculated from average density values given by Donart.[3] These densities are based on 2-ha plots in two sections (20 and 28) within this zone. Studies underway should provide density estimates from a large number of 1-ha plots across the dune zone, and will be used in these calculations when the data become available.

The production of new shoots by sand sage steadily increased throughout the growing season. Assuming the growing season began around April 1 (this study was not funded until July 1, thus no spring data are available), the rate of productivity was about 0.69 $kg \cdot ha^{-1} \cdot day^{-1}$ (100 days from April 1 to July 10) up to the July sampling and about 0.24 $kg \cdot ha^{-1} \cdot day^{-1}$ to the September sampling. This is about 1/3 the earlier rate. The September sampling should be near the peak of biomass accumulation for sand sage, as fall temperatures begin to slow growth. It is difficult to compare the value of 81.0 $kg \cdot ha^{-1}$ for sand sage in 1978 with the value of 261 $kg \cdot ha^{-1}$ for sand sage in 1977 reported by Donart[3] since the 1977 estimate includes all components of growth using a different sampling method.

The production of new shoots by shinnery oak increased to about 68 $kg \cdot ha^{-1}$ in July (0.68 $kg \cdot ha^{-1} \cdot day^{-1}$), but decreased from July to September (-0.18 $kg \cdot ha^{-1} \cdot day^{-1}$). A rather substantial die-back of shinnery oak plants was observed across the dune zone in late summer, the cause of which is unknown. This die-back resulted in a lower standing-crop biomass of shinnery oak shoots in September. In contrast to 1977, where Donart reported that shinnery oak was almost twice as productive as sand sage, these two species had nearly equal rates of productivity up until July when sand sage continued to increase, but shinnery oak did not. A die-back in shinnery oak for 1977 was not reported.[3]

The production of new shoots by mesquite was greatest in the summer. Up until July, the rate of productivity was only 0.039 kg ha^{-1} day^{-1}, but this rate increased to 0.11 kg ha^{-1} day^{-1} during the July-to-September period. Thus mesquite has a productivity pattern different from either sage or oak. The productivity of mesquite in the dune zone was not measured in 1977.[3]

Mesquite also produces new leaves at old stem nodes, thus its production is more complex. Just as with the production of new shoots, mesquite can have flushes of new leaf growth at old nodes at different times of the growing season. At the July sampling, the mean biomass of such new leaves was 0.16 g node^{-1} and 23.2 g plant^{-1}. Based on the mean density estimate for mesquite of 44.5 ind ha^{-1},[3] this gives a standing crop of 1.03 kg ha^{-1} for leaves at old nodes. At the September sampling, the mean biomass of such leaves was 0.40 g node^{-1} and 501.0 g plant^{-1}, resulting in 22.3 kg ha^{-1}. Thus by September, mesquite had a large standing crop of leaves at old nodes relative to July and relative to the standing crop of new shoots (more than double).

The total productivity of forbs, grasses, and subshrubs on the sand dune zone at two times during the growing season is given in Table 5.2. The forbs and grasses (and graminoids) are categorized into annuals and perennials. Of these different life forms (forbs, grasses, subshrubs), perennial grasses had the greatest productivity in 1978 (both samplings). Overall, three-awn (Aristida sp.) were the most productive grasses, followed by the dropseeds (Sporobolus sp.). This same productivity pattern was found in 1977 by Donart,[3] where three-awns were the most productive (mean of 58.5 kg ha^{-1}), followed by the dropseeds (mean of 21.9 kg ha^{-1}). This may indicate a lower production by three-awns and dropseeds in 1978 (26.3 kg ha^{-1} and 12.0 kg ha^{-1} in September 1978, respectively) or it may reflect sampling differences where the 1977 data is restricted to two selected plots in two sections, and the 1978 data consist of a stratified random sampling across the entire vegetated sand dune zone of the study area.

False buffalograss (Munroa) and sandbur (Cenchrus) are the most prevalent and persistent annual grasses across the sand dune zone. Sandbur is the most important in late summer, whereas buffalograss peaks in early summer. In 1977, only sandbur was abundant on the two plots sampled by Donart.[3]

Of the perennial forbs, only Evolvulus was important and persistent, maintaining a biomass of over 4 kg ha^{-1} during the summer. Both Croton dioicus and Senecio multicapitatus were important in the late summer of 1978, but only the former was important in 1977.[3] Evolvulus was not recorded in 1977.

A large number of annual forbs were important in 1978. In the early summer of 1978, Houstonia and Pectis were the most abundant, whereas in late summer, Euphorbia missurica and an Eriogonum species (along with persistent Pectis) were the most abundant. A large number of annual forbs were evident in the early summer sampling that were absent in the late summer sampling.

The production of biomass by the major plant species on the mesa zone of the Los Medaños WIPP Study Area is given in Table 5.3. Mesquite is the only abundant shrub in the zone. Its productivity in late June, comparing the mean biomass per plant, was about equal to that for mesquite in early September in the sand-dune zone. Since no density values for mesquite on the mesa zone are available, it is not possible to compare production on a per-unit-area basis (until such data is available).

The production of blackgrama (B. eriopoda) exceeds that of burrograss (S. brevifolius) on the mesa zone; however, neither species had a very high standing-crop biomass in 1978. Although no comparative data is available at this time, our experience with similar grassland in other areas of eastern New Mexico suggests that the mesa site has a potentially higher productivity. However, conditions were relatively dry at the time of sampling and this zone of the Los Medaños study area remained very dry throughout the summer. There was a distinct gradient of precipitation across the study area in the summer of 1978, with many more storm paths crossing the southwestern (plain zone) and central (dune zone) regions. Thus the mesa zone plants were not resampled after June since no new growth occurred.

The production of biomass by the major shrubs on the flood plain zone of the Los Medanos WIPP study area is given in Table 5.4. Creosotebush (L. tridentata) is the only abundant large shrub in the zone, with some snakeweed as a significant subshrub component. Because this zone was sampled only once during the summer of 1978 we do not know the pattern of productivity of creosotebush, which is typically very dynamic and responsive to precipitation patterns.[4] Also, since at this time we do not have density estimates for creosotebush and snakeweed, we cannot compare this peak (or near-peak) biomass production with other sites for which we have data in the northern Chihuahuan desert.[4,5]

Summary

Data on the production of biomass through the fixation of energy and uptake of nutrients by major plant species on the Los Medanos WIPP study area are presented. For purpose of study, the area was divided into 3 zones: the vegetated sand dune zone across most of the central part, the mesquite grassland-mesa zone across the northeast corner, and the creosotebush plain zone across the southwest corner. Sand sage, shinnery oak, and mesquite are the shrubs with the greatest productivity of new shoot growth in 1978 on the dune zone, combining for over 150 kg ha^{-1}. In 1978 on this zone the smaller life forms were abundant, with annual forbs, perennial forbs, annual grasses, and perennial grasses producing 30.1, 19.5, 26.6 and 45.1 kg ha^{-1}, respectively. These plant groups were more diverse and productive than in 1977. Snakeweed was the only subshrub with any productivity (8 $kg.ha^{-1}$ in September 1978). On the mesa zone, mesquite is the only important shrub and on the plain zone, creosotebush is the only abundant shrub, with productivities of 438 and 648 g $plant^{-1}$, respectively. Because density data are not available at this time, these shrub productivities cannot be compared to other areas, but will be in the future when this data is available.

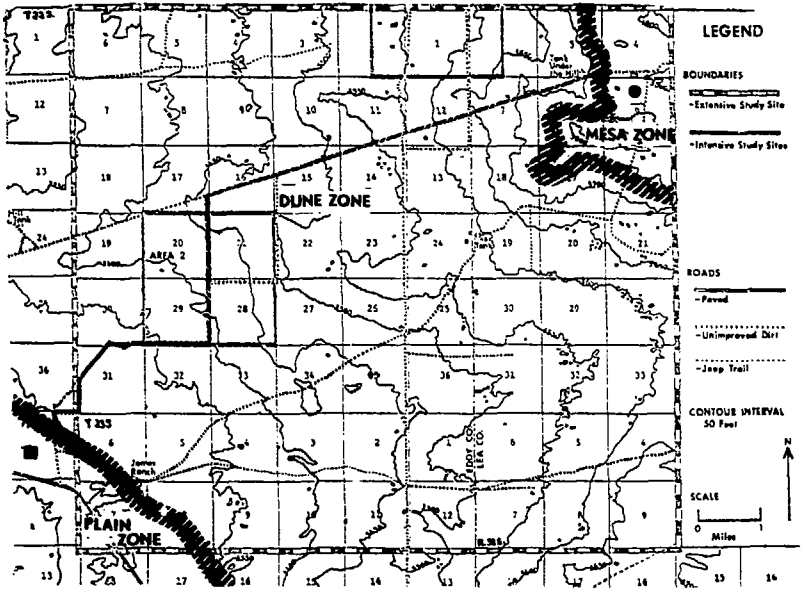

Figure 5.1. Location of the road (-·-·-) along which plants were sampled across the Dune Zone and the location of the sample sites within the Mesa Zone (●) and the Plain Zone (■).

Table 5.1

Production of new shoot biomass by three shrubs occurring in the sand-dune zone of the Los Medaños WIPP study area for 1978

Species	Date	$g \cdot shoot^{-1}$	$g \cdot plant^{-1}$	$kg \cdot ha^{-1}$
Artemisia filifolia (Sand Sage)	July	0.25	22.3	68.6
	Sept	0.12	26.3	81.0
Quercus havardii (Shinnery Oak)	July	0.23	8.30	67.5
	Sept	0.21	7.18	58.4
Prosopis glandulosa (Mesquite)	July	2.62	87.8	3.91
	Sept	2.99	212.9	9.47

Table 5.2

The total density and biomass of annual and perennial forbs and grasses and subshrubs for June and September 1978 on the vegetated sand dune zone of the Los Medaños WIPP area

Life Form of the Species Group*	27 June 1978		2 September 1978	
	Density $No \cdot ha^{-1}$	Biomass $kg \cdot ha^{-1}$	Density $No \cdot ha^{-1}$	Biomass $kg \cdot ha^{-1}$
Annual Forbs	70,733	18.53	12,286	30.08
Perennial Forbs	15,277	8.72	7,508	19.49
Annual Grasses	42,244	16.85	19,794	26.62
Perennial Grasses	57,962	69.34	21,159	45.08
Subshrubs	1,474	1.39	6,143	8.04

*The density and biomass data for each species within these life form groups are given in Chapter 5 of the Complete Annual Report[2]

Table 5.3

Production of biomass by species on the mesquite grassland-mesa zone of the Los Medaños WIPP study area for 22 June 1978

Species	BIOMASS $g \cdot shoot^{-1}$	$g \cdot plant^{-1}$	$kg \cdot ha^{-1}$
Prosopis glandulosa (Mesquite)	1.04 0.36	203.6 235.2*	** **
Bouteloua eriopoda (Black grama)	-	-	196.0
Scleropogon brevifolius (Burrow grass)	-	-	29.6

*Leaves at old stem nodes.
**Density data not available for this calculation.
-Not applicable to the harvest method used.

Table 5.4

Production of biomass by species on the creosotebush plain zone of the Los Medaños WIPP study area for 8 September 1978

Species	BIOMASS $g \cdot shoot^{-1}$	$g \cdot plant^{-1}$	$kg \cdot ha^{-1}$
Larrea tridentata (Creosotebush)	0.088	684.0	*
Gutierrezia sarothrae (Snakeweed)	0.017	0.71	*

*Density data not available for this calculation.

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CHAPTER 6

PLANT SUCCESSIONAL STUDIES ON THE LOS MEDAÑOS WASTE ISOLATION PILOT PLANT (WIPP) AND GNOME SITES, SOUTHEASTERN NEW MEXICO

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Introduction

Structural characteristics of an ecosystem vary directly in relation to the amount and kind of disturbance the system has received. Grazing affects these systems to varying degrees, generally causing a gradual departure from climax (retrogression). However, man-induced vegetation changes are often catastrophic and result in complete denudation of sites where activity is concentrated. Secondary succession advances on these disturbed sites at a rate decided by the severity and extent of the disturbance as well as by the site characteristics, especially precipitation, soil, and topography.

To provide a basis for segregating natural variations (e.g., climatic variations and changes due to animal activities) in plant communities from man-caused variations, Texas Tech University researchers were charged with initiating successional studies on the Los Medaños site. Dynamics of existing plant communities are being studied by comparing diversity and structural characteristics on paired disturbed and nondisturbed sites.

Specific objectives are as follows: (1) to review available literature and document what is known about these kinds of lands; (2) to document plant community structural characteristics on the Los Medaños site; (3) to characterize the specific plant communities on the site with

correlations to soil type; (4) to establish permanent transects and photographic points at strategic locations to monitor long-term vegetational changes; (5) to determine composition and phenology at selected locations near the site; and (6) to coordinate the above activities with data gathering activities of other investigators.

Review of the Literature

Vegetation

Slight differences in either soil or climate may produce pronounced changes in vegetation type; conversely, subtle changes in vegetation type may indicate only slight differences in soil or climatic conditions.[1] Campbell[2] documented plant succession on clayey soils in southern New Mexico. As the kind of clay changed, successional sequences changed. Coville and MacDougal[3] briefly discussed the vegetation from near El Paso to southern Arizona relating the ecological factors responsible for these types of vegetation. Spalding[4] discussed plant associations and habitats of many desert plant species.

Fosberg[5] studied vegetation in the Mesilla Valley of southern New Mexico. He characterized four major vegetation zones: (1) southern desert shrub, (2) salt desert shrub, (3) upper Sonoran, and (4) grassland zones. Although not a community level description, this research related zonal vegetation to specific climatic types. Muller,[6] working independently, published a classic on succession in the creosotebush (Larrea tridentata)-tarbush (Flourensia cernua) association in southwest Texas. He related succession to various erosion cycles and other types of disturbances.

Whitfield and Bentner[7] described two major vegetation types of the southern desert grasslands. The two components, black grama (Bouteloua eriopoda)-tobosagrass (Hilaria mutica) and curly mesquite (Hilaria belangeri)-blue grama (Bouteloua gracilis) are most common as climax types. As retrogression due to disturbance occurs, progressively more

shrubby growth becomes evident. Similarly, Campbell[8] stated that on low sand dune types of southern New Mexico, a large population of honey mesquite is found. He described five successional stages on these dunes: (1) mat stage with low, prostrate annuals, (2) ruderal "weed" stage with large, coarse annual and perennial forbs, (3) a perennial broomweed stage, (4) the Sporobolus (dropseed) stage (the beginning of a grassland aspect), and (5) the black grama climax stage.

Emerson[9] discussed the vegetation in the New Mexico White Sands area. Successful plants must tolerate high concentrations of calcium sulphate. Second, species that cannot tolerate sand inundation are not successful on these dunes. In this area, adventitious roots form at nodes rapidly on seven species as they become buried.

Campbell and Bomberger[10] studied black grama and perennial broom snakeweed (Gutierrezia sarothrae) in southern New Mexico. Drought and overgrazing drastically reduces black grama cover and this grass is slow to revegetate areas as sexual reproduction is slow. On the contrary, broomweed rapidly infests black grama depleted ranges. Many years of judicious use and minimal disturbance are required to increase grama grass cover.

Wooton[11] discussed New Mexico's rangeland and noted its condition, forage plants, and poisonous weeds. He pointed out that wise management was needed to conserve this natural resource. Better systems for control and management of rangeland vegetation were suggested.

Much of the southwestern desert once supported moderately dense stands of grass. As large herbivore grazing intensity increased, shrubs have increased dramatically.[12] Loss of grass with an increased shrub cover has often been accompanied by surface soil loss.[13] Humphrey[14] asserted that desert grasslands are not a true climax vegetation type, but are a subclimax maintained by fire. Extensive wildfires are a thing of the past, thus low trees, shrubs, and cacti have increased dramatically. Similarly, Brown[15] stated that shrubs are the climatic climax in much of the southwest. Periodic drought and grazing have reduced the vigor of

many plants throughout the area. Nevertheless, shrubs come to occupy many sites copiously without disturbances of any kind.

Succession

Tansley[16] defined succession as the "gradual change which occurs in vegetation of a given area of the earth's surface on which one population succeeds the other." The "gradualness" or rate of this change is principally controlled by the macroclimate of an area. There are contrasting viewpoints as to whether succession is unidirectional or bidirectional. Some authors suggest that changes caused by perturbations are not successional changes. Cooper[17] remarked that the term "change" should refer to any successional or retrogressional sequence. Terminology arguments have tended to dampen the enthusiasm of many plant ecologists.

Current American plant ecologists generally agree that several climax types can be found within one geographic area.[18] For example, you might find different climatic-, pyric-, edaphic-, topographic- and biotic-climaxes within short distances of each other. Clements, one of the "Fathers of American Plant Ecology," suggested that only one climax vegetation type would prevail in an area if geological time was considered.[19] Aware that a single climax was an abstraction with, perhaps, no reality, we "manufactured" many terms to identify the observable departures from climax.

Plant communities change in essentially three major ways:[20] temporally, nondirectionally, and spatially. With changes in time, a community may become more complex (ecological succession) or less complex (retrogression). Nondirectional changes involve intracommunity changes where cycles or fluctuations of plants can be noted. Spatial changes are changes from area to area. In particular, those changes across ecotones are most important. Major[21] described time changes within natural vegetation as seasonal, annual, successional, historical, and genetic. Obviously, the first two types are of short duration and easily observable. The latter types, however, require long-term and/or very detailed study.

Succession on sand dunes in arid climates is a very slow process.[22] Early secondary succession following severe disturbances is relatively rapid; however, as you approach the perennial species stages, change is slow. Our observations on West Texas sand dunes show little vegetation change since 1941. Minor oscillations in canopy cover have occurred, but dominant species have been relatively stable. Olson[23] noted that in the upper Midwest, initiation of the climax vegetation stage associated with physiographic stability of sand dunes might require as much as 1000 years.

Man's Impact on Vegetation

Within the last 15 years there has been an active interest in studying the impact of man and off-road vehicles (ORV) on relatively fragile ecosystems. Most of the work has been on coastal dunes and on very arid desert regions near major southwestern metropolitan areas.

Broadhead and Godfrey[24] studied the impact of ORV driving in the Cape Cod National Seashore area of Massachusetts. They found that 300 to 700 passes on a confined path could completely destroy the aboveground parts of plants. Although rhizomes were not destroyed, regrowth was slow. Wind velocities near ground level increased and soil deflation rates increased.

The California Desert has received much ORV abuse, according to Stebbins.[25] This timely review suggests that legislation must be enacted immediately to save this desert from decimation. He suggested that the chances are poor that perennial vegetation will recover on bared areas. Revegetation of these disturbed sites would require large expenditures, with high chances of revegetation failure. Annual plants do not easily reinvade some disturbed areas. Reasons for low germination are not clear.

Vollmer et al [26] found that ORV disturbance in southern Nevada reduced the densities of annual plants. As driving intensity increased, shrub damage increased. Nearly 58% of the shrubs in regularly-driven tracks sustained 81 to 100% damage. In England, Liddle and Greig-Smith[27] described ecosystem damage caused by car traffic. Pressure exerted by a car with driver was 950 g/cm^2 on soft ground and 1500 g/cm^2 on hard

ground. This pressure caused a "crust" in the top centimeter. Subsequent effects on bulk density and soil water properties were pronounced. Similarly, vegetational effects were adverse, specifically seedling establishment.[27] This detailed research quantified the effects of disturbance on many species. A "trampling flora" seems to develop on disturbed areas.

Definitive conclusions, based on statistical analyses, could not be made concerning motorcycle damage to Mojave Desert vegetation.[28] They found a significant loss of herbaceous vegetation and generally less cover per individual plant in disturbed areas. These researchers surmised that subtle site differences could have "masked" the actual detrimental effects of this traffic.

Other studies involving human disturbances on arid land ecosystems have been completed by Vasek, Johnson, and Brum.[29] This research explored the effects of construction of power-lines on the Mojave Desert. Similarly, Vasek, Johnson, and Eslinger remarked that pipeline construction in desert ecosystems destroyed the system.[30] Many centuries might be required for the vegetation to recover.

Carter[31] strongly suggested that a compromise soon be reached between land management agencies and the public. Enforcement of regulations is difficult, particularly when the abuse is on public land. Specific areas should be set aside for the recreationists and their ORVs.

Materials and Methods

Fifteen study sites were selected in 1978 for monitoring change in plant communities (Fig 6.1). Locations were chosen to reflect changes that have occurred, or could occur, due to natural succession, grazing management, and mechanical disturbances such as road building, parking lot paving, soil removal, deposition of soil and other material, and camping (Table 6.1). Five existing fenced exclosures and two proposed exclosures were sampled both inside and outside to provide a measure of natural vegetation change and vegetation change due to livestock management. Five

areas were sampled specifically to provide species composition for bird studies in the major plant communities that occur within and adjacent to the proposed disposal site. One area of active sand dunes near the James Ranch headquarters and the camp area used by project researchers was sampled as a unique disturbance situation occurring within the ERDA 9 locale. The Gnome area used for nuclear testing in the 1960's and located outside the WIPP site per se (Fig 6.2) has had large equipment disturbance, parking lots, paved roads, gravelled roads, soil borrow, and fill areas on-going since 1959. This area has very similar vegetation and climate to the WIPP site so it provided numerous study sites. We also provided vegetation data for the mammal grid, but no permanent vegetation transects are on that grid.

In addition to plant cover and density, notes were made on phenological development of each plant species encountered. Two photos were taken at each transect: one, a close view of the forepart of the transect taken from a 2.5-m height; and the other, a general view of the transect taken 4 m in front of the transect from a 1.5-m height.

Number of transects varied by locale; e.g., exclosure transects have five inside and five outside, whereas disturbed areas on the Gnome Site have three in the disturbance and three out of the disturbed area. Measurements of plant cover and plant density values were taken along the transect. Plant cover values, synonymous with Daubenmire's values[18] measured the percentage of the ground covered by the total natural spread of foliage of the individuals of a species. Since dominance is asserted as much by the roots as by the shoot system, small discontinuities were disregarded if they reflected no more than accidents in the position of the foliage. Bare ground and litter cover were also recorded.

Transects were 30 m lines with ten 50 cm^2 quadrats per line; adjacent quadrats were 208 cm apart. Quadrats were positioned only on the right side of the tape and observers stayed on the left when reading the transect, to minimize observer disturbance. Small steel stakes were put at the diagonal corners of the quadrat to allow accurate repositioning of

the quadrat at successive recordings. Transect summaries by location are tabulated in Tables 6.2 to 6.26.

Results and Discussion

Gnome Site Vegetation Analysis

Contaminated Waste Dump -- Three distinct plant communities and soils are found on this site (Fig. 6.3). Two of these sites reflect extensive soil disturbance while the third, immediately to the north, has an undisturbed profile. Thus three substrates for plant growth are evident: (1) approximately 45 cm of topsoil fill plus the buried original soil on the "dump;" (2) the scraped and truncated profile from whence the fill was obtained; and (3) a normal sequence of topsoil, subsoil, and parent material.

Site 1 is dominated by dropseed species (*Sporobolus* spp.). This genus occurred in all the sample plots on the area with a canopy coverage of 18% (Table 6.2). Density of over 6 plants per 50 cm^2 was found, including both young and mature plants. This suggests that dropseed will continue to dominate the dump until seed sources from other perennials immigrate to the area. Throughout the southwest it is typical for dropseed to rapidly reenter disturbed sites, provided a suitable soil is present. Evidence on the dump suggests that rabbit fecal deposits have been the primary mode of dropseed dispersal.

Secondary perennial grasses on site 1 were plains bristlegrass (*Setaria macrostachya*) and gummy lovegrass (*Eragrostis curtipedicillata*). Lovegrass plants were scattered on the uppermost part of the dune while bristlegrass formed colonies near the periphery of the site. Assuming no further disturbance, the dump may support increased amounts of bristlegrass and hooded windmillgrass (*Chloris cucullata*), a grass located contiguous to the site.

Forbs are not important on the dump. The eight species present are indicative of lower successional stages and probably will never assume aspect or ecological dominance. In addition, no evidence of shrub invasion was noted on the site (Table 6.3).

Site 2 has a rather continuous mantle of finer-textured soil at the surface. With few exceptions, the entire sample transects were on the subsoil (argillic horizon) or on a calcic horizon giving a white appearance.

Small washes on this slightly sloping site are evidence that water infiltration is slow. The resistance to water penetration plus the shallow truncated soil may prevent many plants from reestablishing on the site.

Currently, site 2 supports a sand dropseed (Sporobolus cryptandrus)-purple threeawn (Aristida purpurea) community (Table 6.3). Panicum ramisetum was occasionally common but had not dispersed throughout the area. Similarly, occasional clumps of poverty threeawn (Aristida divaricata) were observed.

Dicots of significance on the site were broom snakeweed and plains blackfoot (Melampodium leucanthum). The blackfoot was the most dense plant on the area, more than four plants per 50 cm^2; however, each plant had a low stature. Even though more abundant than the other species, it is believed to exert only minor ecological influence.

Litter cover on this scraped area averaged 13% in contrast to 42% litter cover on the dump. Many years may be required to increase litter cover since total plant cover is low, and it is suspected that litter is washed down slope during intense rain storms.

The undisturbed counterpart (site 3) of the previous two sites is a high range condition honey mesquite (Prosopis glandulosa)-black grama community. Sand dropseed and purple threeawn were occasionally found adjacent to the continuous mats of black grama. Only three other grasses

were observed in transect plots while hooded windmillgrass, bristlegrass, and bush muhly (Muhlenbergia porteri) were noted when traversing the area (Table 6.4).

Plains blackfoot again was the most abundant forb on this site, with a density of 1.3 per plot. Other significant forbs were grassland croton (Croton dioicus) and silverleaf nightshade (Solanum elaeagnifolium).

Broom snakeweed was rare in the area while soapweed (Yucca sp.) and catclaw mimosa (Mimosa bluncifera) were common. Occasionally southwest rabbitbrush (Chrysothamnus pulchellus), sand shinnery oak (Quercus havardii) and ephedra (Ephedra sp.) were noted in plots. Feather dalea (Dalea formosa), prickly pear (Opuntia sp.), and javelinabush (Ziziphus ericoides) were found in the vicinity of plots.

Evidently the dump and scraped areas supported similar kinds and amounts of plants prior to disturbance. It is unlikely that the scraped area will reach a high successional stage within the next century. Additions of organic residues obviously would "speed up" the successional process but costs would be high. The dump, because of the added soil, evidently could support black grama. Earlier cited research suggests that this grama has low sexual reproduction potential and depends primarily on asexual means of spreading.

Salvage Yard -- The Salvage Yard on the Gnome site is located northwest of the Contaminated Waste Dump. Aspect at this site is to the south-southwest. Undisturbed soil adjacent to the Salvage Yard scrape is similar to the soil adjacent to the dump. Both this site and the dump were disturbed in 1969, thus similar seral stages should be evident.

A broom snakeweed-purple threeawn community is found on the yard (Fig. 6.4). Plains blackfoot is again prominent but is not ranked as a community dominant (Table 6.5). Other grasses occasionally found on the scrape are sand dropseed, poverty threeawn, red threeawn, and fluffgrass (Erioneuron pulchellum).

Besides the blackfoot, forbs common in the area were grassland croton and silverleaf nightshade. Only five other forbs were sampled in quadrats, while three more dispersed species were within the area.

Shrubby growth was insignificant with only an occasional soapweed and catclaw mimosa. It is unlikely that shrubs will reinvade quickly because of the hardened substrate surface. Surface water runoff is evident and soil-plant-water relationships are necessarily poor. Eighty-seven percent of the soil surface was not covered with litter. Total living plant cover was low.

Just to the east of the scrape was a soapweed-black grama community (Fig. 6.4). The grama had a frequency of 97%, canopy coverage of 29%, and density of 11 plants per quadrat (Table 6.6). This dominant exerts a strong ecological control on the area and probably will not be replaced unless a severe disturbance occurs. Within the grama matrix are occasional threeawns, vine mesquite (Panicum obtusum), hooded windmillgrass, and sedge (Cyperus sp.).

Forb density and cover are not high; however, the forb population is diverse with 12 species recorded within the 30 quadrats sampled. Three additional forbs were noted while traversing the area.

Shrubs found on the site besides soapweed included two cacti species, ephedra, catclaw mimosa, and mesquite. As long as this site is left undisturbed, shrubs should not increase drastically. The soapweed may be expanding slowly as young plants are visible; particularly if an older, contiguous plant had died.

Productivity and speciation on the scrape could be increased by ripping the soil to allow more water to enter and allow better disseminule-soil contact.

Warehouse Area -- The Warehouse Area has been disturbed twice--in 1962 and 1968. All A horizon soil (topsoil) has been removed and replaced

with 30 to 45 cm of caliche with an asphalt-gravel topping. Topographically, the area is flat and currently supports lower successional species. Height of plants on the site may average 1 m.

It appears that wherever the asphalt covering was broken, seeds have germinated. Because of apparently low surface evaporation rates and widely-spaced plants, stature of the plants on the gravel-asphalt areas is higher than on adjoining areas.

Because of the prevalence of sand sagebrush (Artemisia filifolia) and silver bluestem (Bothriochloa saccharoides), the community was named Warehouse Area (Fig. 6.5). The bluestem has a frequency of 27% and coverage of 2.8%. Secondary grass species present were threeawn, fluffgrass, bristlegrass, and gummy lovegrass.

The most abundant forbs on the warehouse pad were annual buckwheat (Eriogonum annuum) and horsetail conyza (Conyza canadensis). Minor amounts of camphorweed (Heterotheca latifolia), silverleaf nightshade, and bluet (Hedyotis humifusa)* were locally present. These and the occasional other forbs were all early secondary succession species.

Litter accumulates on this substrate more rapidly than on all preceding sites. As plant material becomes detached and falls to the surface, there is little opportunity for rapid decomposition. No distinct humic material was noted below the recognizable litter material. Without further deterioration of the asphalt-gravel, vegetation compositional changes may be slow (Table 6.7).

Just to the east of the warehouse pad, the nondisturbed comparison transects were established (Fig. 6.5). This site has a deep (greater than 150 cm) soil overlying a sandy clay loam calcic horizon. A fine sandy loam texture prevailed to a depth of 50 cm before reaching the argillic horizon.

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*Synonymous with Houstonia humifosa; see Chapter 3.

Black grama was noticeably absent on this site, being replaced primarily by sand dropseed (Table 6.8). The vegetation currently was classified as a sand sagebrush-sand dropseed type. The second most abundant shrub was sand shinnery oak with minor amounts of honey mesquite, broom snakeweed, and soapweed.

At the time of the survey, fleabane (Erigeron sp.) was the most abundant forb. The area was traversed on July 28 at which time silverleaf nightshade had replaced the fleabane as being most abundant. Thirteen forb species were recorded from sample plots whereas only one, groundsel (Senecio spartoides), was found elsewhere in the area.

Sand dropseed had a canopy coverage of 11% with a density of 2.3 plants per 50 cm^2. All other grasses had less than 1% cover.

West-Northwest of Shaft -- The soil at this location has a loamy, fine sand surface overlying a sandy clay loam subsoil at 40 cm. No impermeable layer was found which might restrict plant root penetration. Six transects with 60 quadrats were sampled in this area. Topography is relatively smooth with perhaps a 2% slope to the northwest.

The area has some heterogeneity which makes a precise plant community designation difficult. Black grama and bush muhly are locally abundant and form major inclusions within this honey-mesquite, broom-snakeweed, sand-dropseed community (Fig. 6.6). The mesquite was only scattered throughout the area but was the more predominant shrub in the uppermost vegetation layer. Similarly, soapweed was conspicuous throughout the area.

Sand dropseed was evenly dispersed throughout the area with a 60% frequency and 4.5% canopy coverage (Tables 6.9 and 6.10). Black grama was recorded in 35% of the plots with much of it found in transect 17. Threeawns, bristlegrass, gummy lovegrass, hooded windmillgrass, and sandbur (Cenchrus incertus) were of low importance throughout the area.

Dosedaisy (Aphanostephus sp.) was the most abundant forb throughout the area. Blackfoot was only common on one transect. Silverleaf nightshade and grassland croton had pronounced clumped distributions within this area. Annual buckwheat and spectaclepod (Dithyrea wislenzii) were only occasionally prevalent.

This area is similar to undisturbed sites at the Salvage Yard and Contaminated Waste Dump except that black grama is less abundant. As succession proceeds, the grama should increase, dropseed will decrease, and early seral stage forbs will become less numerous.

Southwest Pad -- This area was disturbed when the topsoil was removed in 1959. Currently, there remains 20 cm of caliche and sand overlying a fine sandy loam 131 horizon. The pedogenic calcic horizon is more than 150 cm below the current surface. At a depth of 40 cm, sandy clay loam textures are evident.

In contrast to the Warehouse Area, this pad is relatively devoid of vegetation (Fig. 6.7). The dominant grass is the mat-forming fluffgrass (Table 6.11). It is relatively uniform over the pad with a frequency of 60%, a cover of 1.3%, and a density of 2 plants per 50 cm^2 quadrat. Other grasses recorded were threeawn, bristlegrass, and sand dropseed. This pad can best be described as a broom snakeweed-fluffgrass community.

About 84% of the pad is barren with litter and plant cover making up the other 16%. Only scattered forbs were observed on the site. Camphorweed was the most common with minor amounts of groundsel, woollywhite (Hymenopappus sp.), and bladderpod (Lesquerella sp.).

The undisturbed adjacent community to the northeast of the pad was described as a sand shinnery oak-honey mesquite-sand dropseed type (Fig. 6.7). Sand dropseed has slightly more than 9% cover with 3 plants per quadrat (Table 6.12). Small colonies of fringed signalgrass (Brachiaria ciliatissima) were found throughout this site; and like other grasses on this site, its cover and density were much less than 1%.

At the time the southwest pad was sampled, fleabane was the dominant forb with a cover of 3.2% and a density of 4.2 plants per 50 cm^2. Occasional forbs with less than 1% cover included camphorweed, annual buckwheat, grassland croton, and western ragweed (Ambrosia psilostachya).

Sand shinnery oak dominated the shrub layer with lesser amounts of sand sagebrush, mesquite, and soapweed. The oak appeared in 33% of the quadrats with a cover of 14.3% and a density of 5.9 oak stems per plot. No mesquite was recorded in plots, however, its cover was believed to be of enough ecological importance to suggest a codominance with the oak.

This community has evidently been disturbed in the past as some sandbur, signalgrass, and other invaders are present. Without a detailed soil physical analysis, this site appears to be sandier than all previously described Gnome sites. The common occurrence of oak might verify this. Moreover, the notable absence of black grama seems to indicate a soils change.

Pad South of Shaft -- This pad, constructed in 1963, has substrate consisting of 20 cm of highly compacted C material (caliche) overlying a clay base. The surface is very dense, thus few plants have become established on the area. Over 99% of the soil surface is exposed (Fig. 6.8). Because of this, no community designation is given.

In the 30 sample quadrats only camphorweed, sand sagebrush, and threeawn were found in nonsignificant quantities (Table 6.13). Without further study or knowledge of other possible man-caused disturbances, we cannot speculate why the Southwest Pad was more vegetated than this area.

The adjacent undisturbed area has been designated as a sand shinnery oak-mesquite-sand dropseed type (Fig. 6.8). Oak averages over 15% coverage and the number of stems is slightly more than 7.5 per quadrat. Mesquite is present on the site but was widespread with a low cover value. An occasional soapweed was also present, but its cover and density were low.

Sand dropseed was the dominant grass in the area. Black grama had a 10% frequency with only 1% cover. This grass was only recorded on three contiguous quadrats pointing out its clonal (clumped) distribution on the southern portion of the Gnome site. Giant dropseed (Sporobolus giganteus) was common in the area, as was fall witchgrass (Leptoloma cognatum), but neither occurred commonly within this area. An occasional sandbur was found but was not common.

Bluets, an annual, had the highest frequency of any forb in this area. Annual buckwheat was common but not dispersed throughout the area. Nine other forbs were recorded but are considered unimportant ecologically on this site.

1977 Pad -- The recently constructed pad at the north entrance of the Gnome site was sampled, showing no higher plant life present during the 1978 sampling period (Fig. 6.9). Immediately to the south, the comparative transects on an undisturbed site were established (Fig. 6.9).

This area was tentatively classified as a mesquite-threeawn community although dropseeds were prevalent. Threeawn had a canopy of 4.7% with 1.8 plants per quadrat (Table 6.14). The dropseeds covered 3.9% of the area and an average 1.2 plants were counted in each quadrat. An occasional hooded windmillgrass was recorded while bristlegrass was rarely located in this area.

Broom snakeweed, the most common dicot in this area, could possibly be elevated to the layer dominant status. We believe, however, that threeawn is ecologically more important in the herb strata. Catclaw mimosa was randomly located within the area as was soapweed. Some tasajillo (Opuntia leptocaulis) was also observed away from the sampling line. Sand sagebrush was only locally abundant in the area.

Plains blackfoot was the most abundant forb in the area and achieved similar rank as in the Contaminated Waste Dump scrape area and the Salvage Yard scrape. Minor amounts of grassland croton, silverleaf nightshade, groundsel, and four other forbs were recorded.

Evaluation -- Evaluation of aerial photographs and ground truth data suggests that two major plant associations are found on the Gnome site: mesquite-black grama and mesquite-sand shinnery oak-dropseed types. The soil has previously been mapped as a Kermit-Berino complex. Our data suggest that the northeastern quarter of the site has a more shallow soil profile overlying caliche than to the south. It also appears that the southern part of this area has a sandier surface soil than to the north.

Several seral stages of vegetation development are notable. First, the area north of the Contaminated Waste Dump, in our opinion, is relatively stable and may be close to climax. According to the literature, black grama should be the climax dominant grass at this site. In addition, weedy annuals are not common in the area. The area west-southwest of the shaft is probably seral to the above site.

Scraped and/or caliche-asphalt-gravel pads cannot be accurately related to climax since the substrate has been changed so drastically. Given sufficient time, this matrix will disintegrate allowing more species to enter. However, there is no way to predict accurately when stability will be reached.

South of the shaft, a subtle soil change is noticeable. Taller dropseeds become more important as black grama decreases. More oak is found on this sandier soil. Other arenophilic plants are also evident in the area (Table 6.15).

It appears that compacted caliche pads present a more formidable habitat for plants than does gravel-asphalt. Perhaps substrate temperatures are sufficiently high that germinating disseminules cannot survive. Also the density-hardness of the caliche may prevent root growth.

WIPP and Contiguous Areas Vegetation Analyses

The WIPP Site includes many different combinations of habitat factors allowing a diverse array of plant communities to form. Because of the

magnitude of sandy soils and because of their proximity to the proposed waste dispersal site, greater emphasis on sampling was placed on the dunal systems. Within the dunes, representative areas were selected for vegetation analyses. Obviously, not all the variability was sampled because of time-labor constraints.

This portion of the report discusses the vegetational analyses on the (1) Nash Draw, (2) Red Tank, (3) Highway Exclosure, (4) Exclosures-to-be-Constructed, (5) Two-ha Exclosures, (6) Campsite, (7) Oak and Mesquite Bird Grid, and (8) Mesa Shortgrass Areas (Fig. 6.1 and Table 6.1).

Nash Draw -- The Nash Draw Exclosure supports a creosotebush (*L. tridentata*), bush muhly (*M. porteri*) plant community (Fig. 6.10). Canopy cover of creosotebush is slightly over 10% with a density of 0.3 shrubs per quadrat (Table 6.16). Bush muhly covered 7% of the area and had a density of 0.6 plants per plot. The only other commonly occurring grass within the exclosure was sand dropseed with about 1% cover and 0.5 plant per plot. The soil at the Nash Draw site has 5 cm of fine sandy loam B material. A calcic horizon then continues to 50 cm and abruptly enters a buried gravelly sandy clay loam. The nature of this soil restricts water movement and rooting depth of plants.

Two woody or semiwoody plants prevalent besides creosotebush were broom snakeweed and honey mesquite. Mesquite cover was about 4%, while snakeweed had more than 8% cover.

Outside the exclosure, with cattle grazing, creosotebush cover was about 9%, while bush muhly cover was 1.9% (Table 6.17). Creosotebush outside the protected area was not very different from that in the non-grazed exclosure. Contrarily, the climax decreaser bush muhly covered more than three times as much soil surface when protected from grazing.

Red Tank Area -- The soil near and within the Red Tank Area has a loamy fine sand A-1 horizon 20 cm thick. The B horizon continues to 120 cm until a calcic horizon (Cca) becomes evident. Below 35 cm, sandy

clay loam textures predominate. No restriction to root development could be found in this soil.

A marked contrast in vegetation development was noted within and outside of this exclosure (Fig. 6.11). Severe livestock trampling damage was evident where animals grazed. Gradual recovery of plants was found inside the fence where a shinnery oak-sand dropseed-purple threeawn community prevailed (Table 6.18). Outside the fence an oak-purple threeawn type was present (Table 6.19). Livestock overgrazing has caused extensive deterioration of vegetation over much of this area. Many low successional weeds as sandbur, false buffalograss (Munroa squarrosa), groundsel and pectis (Pectis papposa) were common outside the exclosure.

Sand paspalum (Paspalum setaceum) and fall witchgrass (Leptoloma cognatum) were common inside the fenced area but only occasional outside. Similarly, sand sagebrush had three times more cover outside than inside the exclosure. The entire complement of plants suggest three things: (1) the entire Red Tank Area has received extensive overgrazing for many years, (2) presence of fall witchgrass indicates that the sandy surface mantle is not over 20 to 30 cm deep throughout the area, and (3) species diversity on this site becomes greater as the level of disturbance increases.

Highway Exclosure -- Vegetation and soil found at this exclosure were not much different from the Red Tank Area. Protection from livestock grazing has allowed grasses to increase while the dominant shrub, shinnery oak, has lower canopy coverage within the exclosures.

Inside the exclosure is an oak-dropseed-fall witchgrass community, while the outside area is best described as an oak-fall witchgrass-purple threeawn type. Canopy cover of oak was 7.2% inside and 13.8% outside the exclosure (Table 6.20). Number of oak stems was also higher, 1.9 vs 1.2 where grazing was allowed. Sand sagebrush was common outside the exclosure but rare within the fenced area (Table 6.21). Soapweed, on the other hand, was more abundant where grazing had been excluded. Reasons for this are not clear. Perhaps winter livestock grazing killed the soapweed.

Grasses found on this site, other than the dominants, included poverty threeawn, fringed signalgrass, hairy grama (Bouteloua hirsuta), tumble lovegrass (Eragrostis sessilispica), sand paspalum, black grama, and false buffalograss. Both gramas were relatively rare outside the exclosure while others were locally common in both conditions.

At this time it is difficult to predict the terminal plant association within the exclosure. Obviously, black grama and dropseeds are key species and a part of this climax.

Exclosures-To-Be -- Two 8.3-ha exclosures are planned for conducting controlled experimentation of human impact upon the sandyland ecosystem. One hundred quadrats along 10 transects have been sampled to obtain pretreatment measurements. The soil characterizing both areas is the Berino series. An A horizon, 25 cm thick, overlies the B horizon to a depth of 120 cm. Below this is found the Cca horizon.

The section 15 site is in poor range condition and supports a shinnery oak-purple threeawn-false buffalograss community (Fig. 6.12). In this area oak has a cover of 9.5%, while sand sagebrush covers about 3% of the area (Table 6.22 and 6.23). Mesquite was observed in the area, however, none was recorded in quadrats.

Purple threeawn covered approximately 2% of the ground and false buffalograss had a cover of about 3%. Other grasses contributing to the composition were sand paspalum, sandbur, fall witchgrass, black grama, hairy grama and dropseed.

No single forb dominated the aspect but pectis was most often recorded. Secondary amounts of bindweed heliotrope (Heliotropium convovulaceum) were found, especially on the more barren sand surface.

To the southwest in section 20, a much improved oak range was observed (Fig. 6.12). Less than 2% canopy cover of this shrub was recorded with a stem density of a little over 0.3 stem per 50 cm^2

(Tables 6.24 and 6.25). Sand sagebrush was a subdominant within this area and does not appear to be increasing. Only occasional soapweeds and mesquite completed the shrub layer.

Although considerable bare sand exists in this area, grass composition is vastly different from the section-15 land. The taller dropseeds--probably giant (S. giganteus)--predominate in the herb layer. Tentatively, this community will be described as a sand shinnery oak-giant dropseed type.

Other species in the grass flora included purple threeawn, fall witchgrass, false buffalograss, and sandbur. Each of these had less than 1% cover and density values were low. Forbs were relatively common within this area but all had low cover and density values.

Two-ha Exclosures -- One exclosure was located in the northeast quarter of section 20. The eastern part of the fenced area has a rather uniform cover of oak, while to the west clumps of mesquite were evident. Because this exclosure was recently constructed, no vegetation differences from the inside to the outside were noted. Vegetation on both areas will be discussed together. A sand shinnery oak-dropseed community dominates the area. At selected locations, mesquite could logically be a codominant, but it was not ecologically important over a major portion of the area.

Sand dropseed has a cover of 6.7% throughout the area with a density of 1.3 plants per sampled quadrat. Purple threeawn, poverty threeawn, and false buffalograss regularly occurred in transect plots but assumed no dominant ranking. Hairy grama and sandbur were occasionally recorded while scattered colonies of black grama and bristlegrass appeared in the area.

Annual buckwheat and pectis were the two more abundant forbs but had low cover values. Several other forbs were recorded along the transects but they did not commonly occur within plots.

In section 28, the second 2-ha exclosure was sampled (Fig. 6.13). Comparative transects were run adjacent to the nearby WIPP crew campsite to get measurements of human disturbance effects upon this fragile system. Five transects with 10 quadrats per transect were evaluated.

Both the camp area and exclosure are considered shinnery oak-mesquite-threeawn communities. Sand dropseed was relatively common in the area but had less than 1% canopy cover with less than 0.5 plant per quadrat. Fall witchgrass, tumble lovegrass, and poverty threeawn were locally abundant within this area.

Campsite -- Insufficient time has elapsed to determine human impact upon vegetation at the campsite proper. By the end of the field season, a notable decline in annual species was evident. Some breakage damage was observed on the shrubs and taller perennial forbs.

Human trampling damage to an ecosystem is quite different from ORV damage as man selectively picks his traverse route. Vehicular damage, on the other hand, is less selective and tends to harm a greater number of species. When observing human traverse through an area, a distinct observation can be made. People generally do not step on large, clumpy, bristly or hard plants. Thus, plant species found between the above types receive the major damage. Single-stemmed, low-growing annuals are most susceptible to damage. Then prostrate and short-lived perennial forbs will decline. These will be followed by the more vertically growing forbs that produce distinct rosettes prior to flowering shoot elongation. These plants, if growing within the canopy of a large plant, are not damaged. Two examples of these forbs within this area are erect dayflower (Commelina erecta) and four o'clock (Mirabilis sp.).

Bunch grasses are seldom trampled upon, while prostrate low grasses receive more severe damage. On the campsite little damage was exerted upon the threeawns whereas false buffalograss, fall witchgrass, and fringed signalgrass are more regularly trampled. At this time it is impossible to speculate upon the length of time required to reduce the vigor and eventually the density of these species.

We think that an obvious "trampling flora" will develop within heavily utilized areas. The thin stemmed annual forbs will be the first plants to succumb. Prostrate range plant decline will soon follow.

Below is a listing of plants found in and near the campsite area followed by their susceptibility to trampling evaluation. There may not be full agreement with the ratings because growth and development of these plants are not always the same:

Campsite Area Plants	Susceptibility to Trampling
(1) Pectis	easy
(2) Hedyotis (= Houstonia)	easy
(3) Linum	easy
(4) Euphorbia (mat)	easy
(5) Talinum	easy
(6) Euphorbia (vertical)	moderately easy
(7) Heliotropium	easy
(8) Palafoxia	moderately easy
(9) Erigeron	moderately easy
(10) Dithyrea	moderate
(11) Hymenopappus	moderate
(12) Phyllanthus	moderate
(13) Caesalpinia	moderate
(14) Quercus	difficult
(15) Prosopis	difficult
(16) Aristida	difficult
(17) Sporobolus	difficult
(18) Bouteloua	difficult
(19) Gutierrezia	difficult

By the end of next year's field season a more precise evaluation of these ratings will be possible.

Mesa Shortgrass Site -- The soil on the mesa transect area is a Kimbrough sandy clay loam. It is characterized by having an A-11 horizon, 7.5 cm thick; an A-02 horizon up to 25 cm thick, then a relatively indurate Ccam horizon below 25 cm. Because of the shallowness of the soil at this site, plant root penetration will be inhibited. Inclusions of deeper soil are found at the base of each mesquite clump. This may reflect deposition of soil from adjacent areas or erosion of topsoil between the mesquite down the gradual slope to the west.

This community is characterized as being a mesquite-black grama-fluffgrass type. The grama covered 6% of the area with a density of 6 plants per quadrat sampled (Table 6.26). Fluffgrass covered 2.9% of this area. In local areas away from the mesquite, burrograss (Scleropogon brevifolius) and ring muhly (Muhlenbergia torreyi) became common. Within the mesquite clumps, bristlegrass and bush muhly were common.

Bladderpod was the most common forb on this site. A small mallow and borage were common but had low cover and density values. Silverleaf nightshades could be occasionally found.

Shrubs were scattered with mesquite having a little over 4% cover and a density of 0.4 plant per 50 cm^2. Perennial broomweed, a half shrub, was common along all transects but its cover and density were low.

Oak and Mesquite Bird Grids -- Soil at the oak-mesquite bird grid is similar to other Berino soils within the area. Surface and subsoil characteristics should present no restrictions to plant growth. Depth to the Cca horizon at this site was more than 180 cm.

A shinnery oak-sand dropseed-sand paspalum community predominates in the area. The oak covers 14% of the area but its cover is highly variable throughout the area going from 29% on transect 42 to 3.7% on transect 45. Locally, soapweed is important but has no dominance ranking at the community level.

Sand dropseed covers 3.2% of the oak-bird transect areas, while sand paspalum covers slightly less than 1%. Purple threeawn, sandbur, fall witchgrass, black grama, and hairy trideus (Erioneuron pilosum) could be found in the area by walking around.

Bluet and pectis were the most abundant forbs in this area. Leaflower (Phyllanthus sp.) and heliotrope were evident throughout this area. Other forbs included grassland croton, woolly dalea (Dalea lanata), annual buckwheat, and sand lily (Mentzelia sp.).

The soil at the mesquite-bird transects are not unlike surrounding areas except more wind erosion activity is observable. The calcic horizon has a depth of over 135 cm. A distinct sandy clay loam layer is found in the soil profile. Topography is very hummocky with coppice dunes throughout.

The plant community dominating this area is mesquite-sand shinnery oak-sand dropseed (Fig. 6.14). Each hummock supports shrub growth to some extent with mesquite forming the dense thicket type growth. High variation was found in the vegetation from one transect to another. For example, no herbaceous species were recorded on transect 32 while eight were found on transect 36. Total plant canopy cover per transect varied from 3.6 to 23.5%, again pointing out the variation in the less stabilized parts of the WIPP site.

Summary

Color aerial photographs of the WIPP and adjacent area sites were used to differentiate the vegetation into relatively homogeneous units. When completed, the mapping units were traversed to note variations in vegetation structure and compostion. Notes on soil differences and grazing use were taken.

The most feasible way to study plant succession on rangeland is to look for nongrazed and grazed areas. Thus, we examined existing BLM

(Bureau of Land Management) exclosures (protected areas) to seek areas for establishing permanent transect plots. Within each exclosure and immediately outside, permanent transect lines were established. The lines, 30 m in length, had 10 equidistantly-spaced, 1/2-m^2 quadrats placed. Within these quadrats, cover, density, and frequency of plants were recorded.

A total of 144 lines was sampled. Number of quadrats sampled at each site varied from 30 to 50. Photographic records of each line were recorded as well as site factors. No statistical analyses of data have been completed as more data are required to construct a predictable model of vegetation change.

The Gnome area encompasses severe human disturbances upon a sandy soil. Topsoil removal, gravel-asphalt layers, and caliche removal have seriously changed the substrate for plant growth. With this level of disturbance, many years of secondary succession will be required to re-establish a good plant cover. It will be extremely difficult to predict when stability will occur on much of this area because site factors have changed so drastically.

Three major vegetation associations are found on the WIPP site. Various departures in vegetation structure and composition can be attributed to differential grazing use causing many specific communities to form. Communities were named according to the dominant plant in the shrub and herbaceous layer.

The dominant grass genera throughout the matrix of sandy soils were Sporobolus and Aristida. Erioneuron was the most important grass genus on the Mesa Shortgrass prairie while Bouteloua and Muhlenbergia were most important in much of the Larrea type.

Interseasonal fluctuations in plant populations became notable, especially after precipitation events. Ephemerals are important components of the vegetation in this arid land system but are probably not the key

indicator species for community designations. More data need to be collected before specific community nomenclature can be used. Seral stages and ecological relationships are not clear at the end of the first field season.

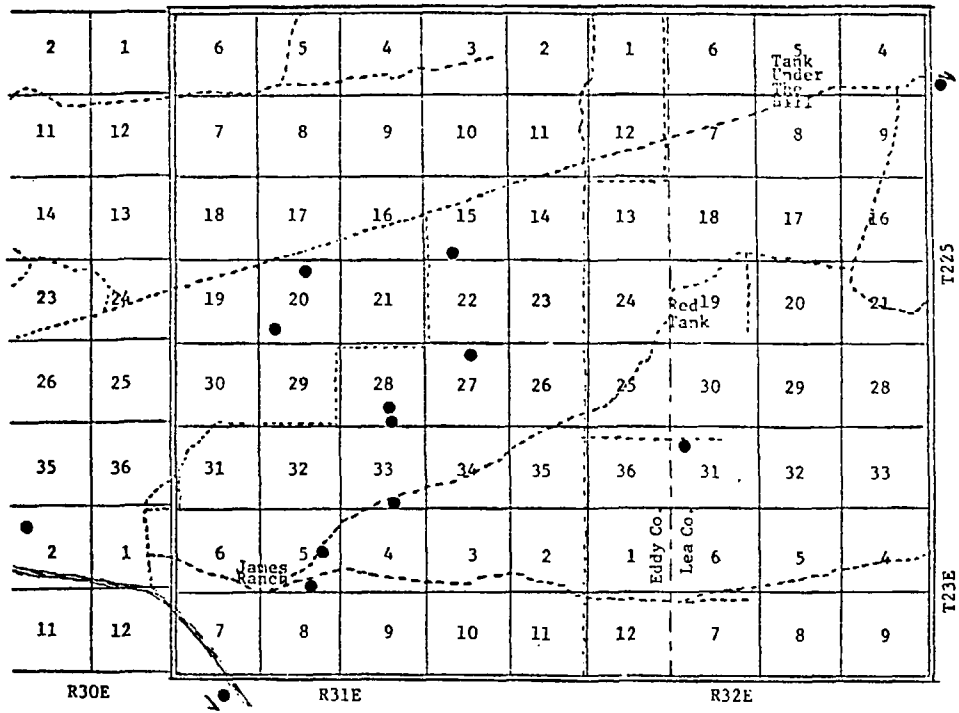


Figure 6.1. The WIPP site southeast of Carlsbad giving locations of plant successional studies.

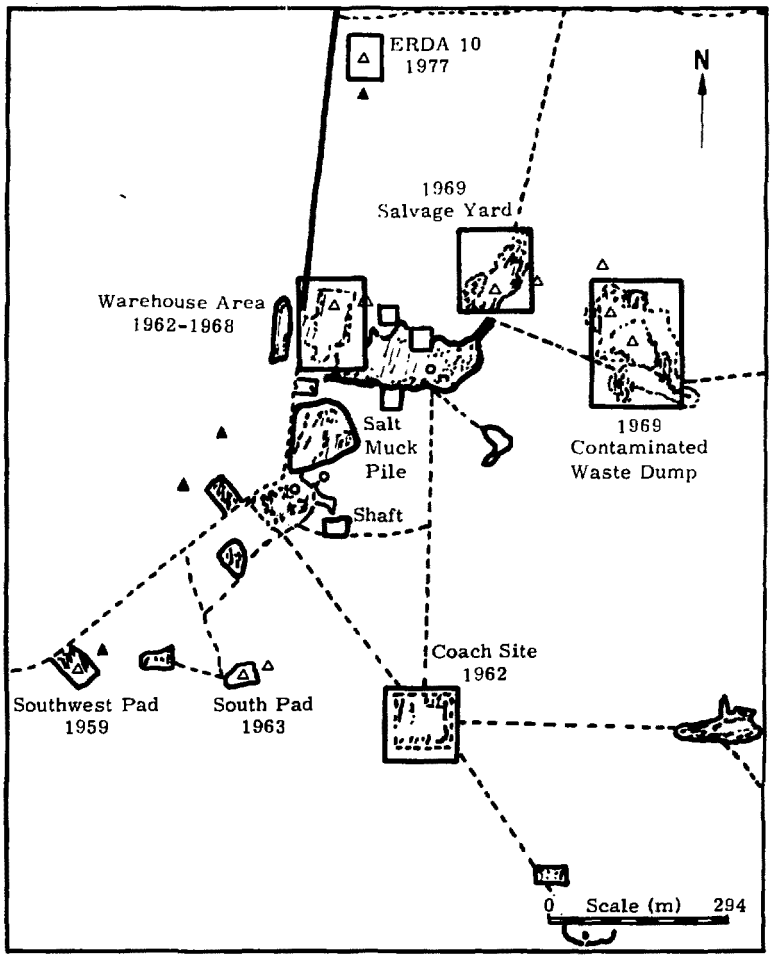
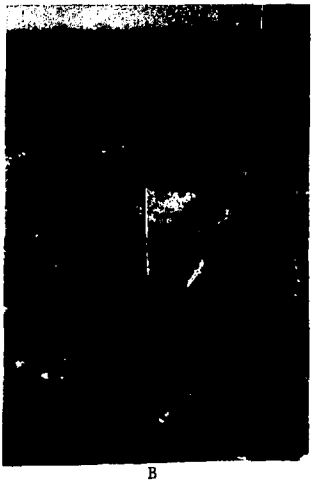
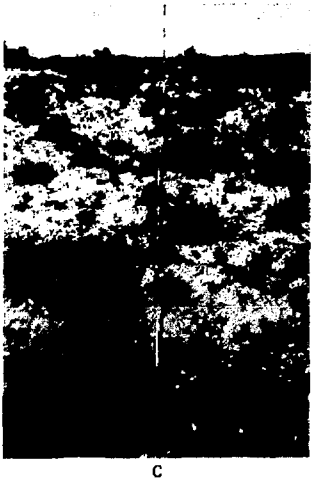


Figure 6.2. Solid triangles locate all study sites on the Gnome Site. Year when site was disturbed is given. Shaded areas depict severe soil disturbance.

A



B



C

Figure 6.3. Permanent Transects on the Gnome Contaminated Waste Dump. A is nondisturbed, B is the dump pile, and C is the scraped area.

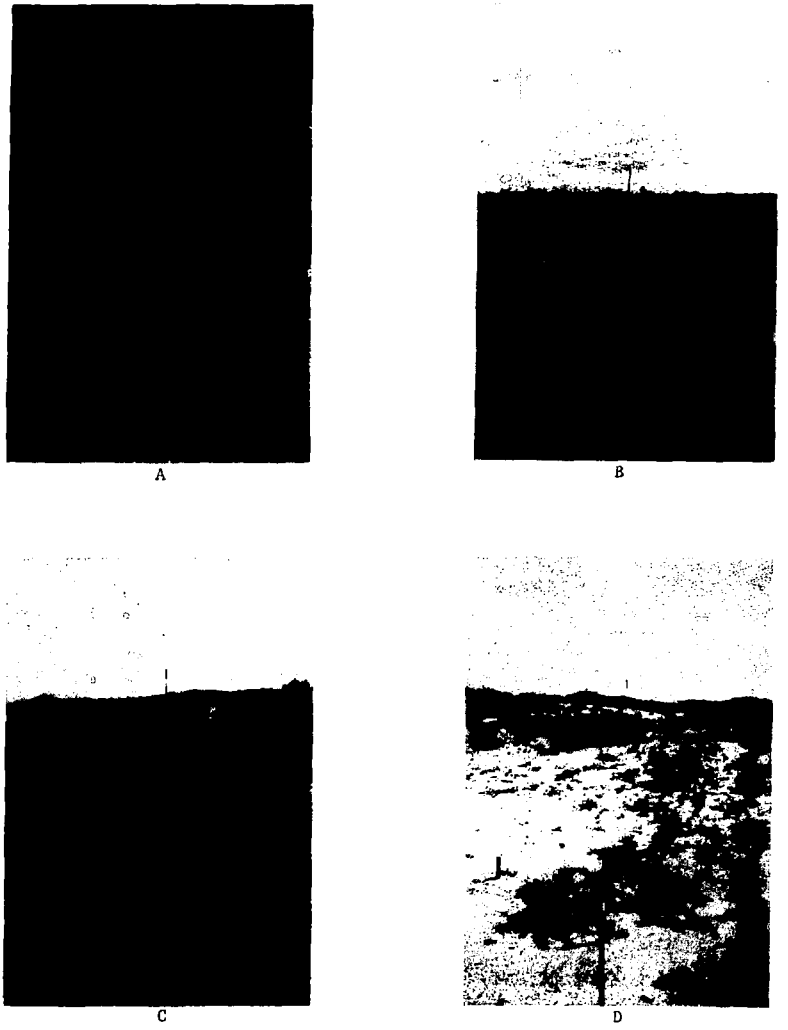


Figure 6.4. Transects at the Gnome Salvage Yard. A and B are the undisturbed comparison while C and D are the scraped area.

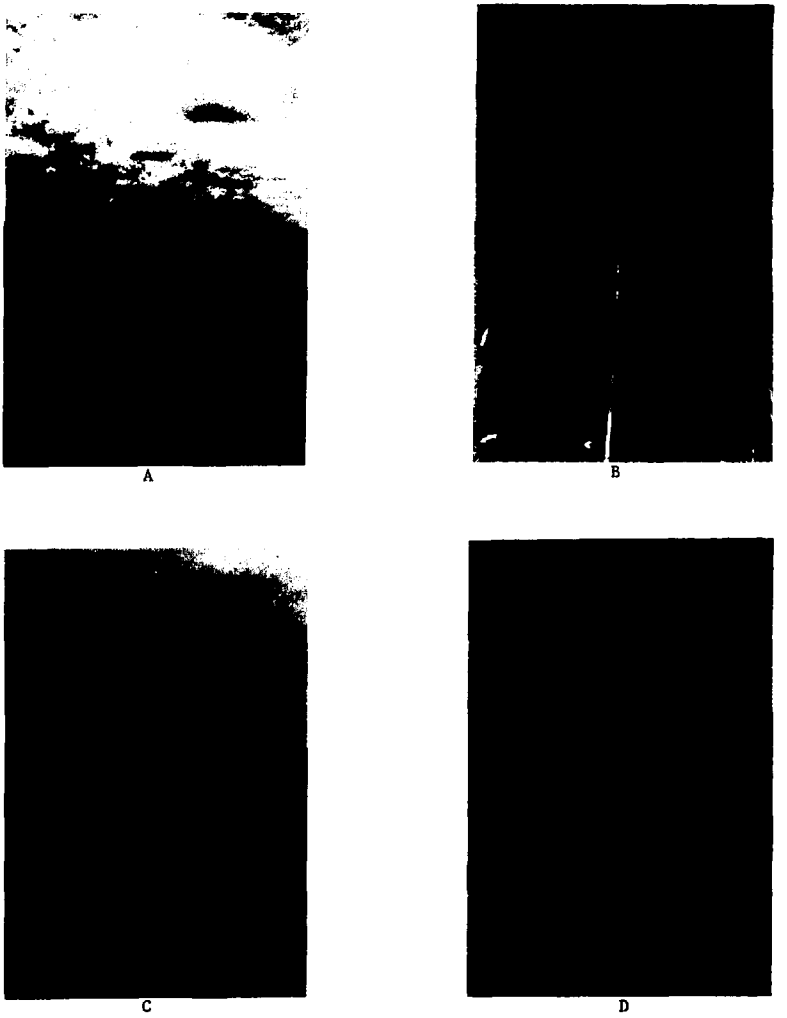


Figure 6.5. The Warehouse Area on the Gnome Site is characterized by a gravel-asphalt base, photos C and D, while the comparison area A and B have fine sand substrate.

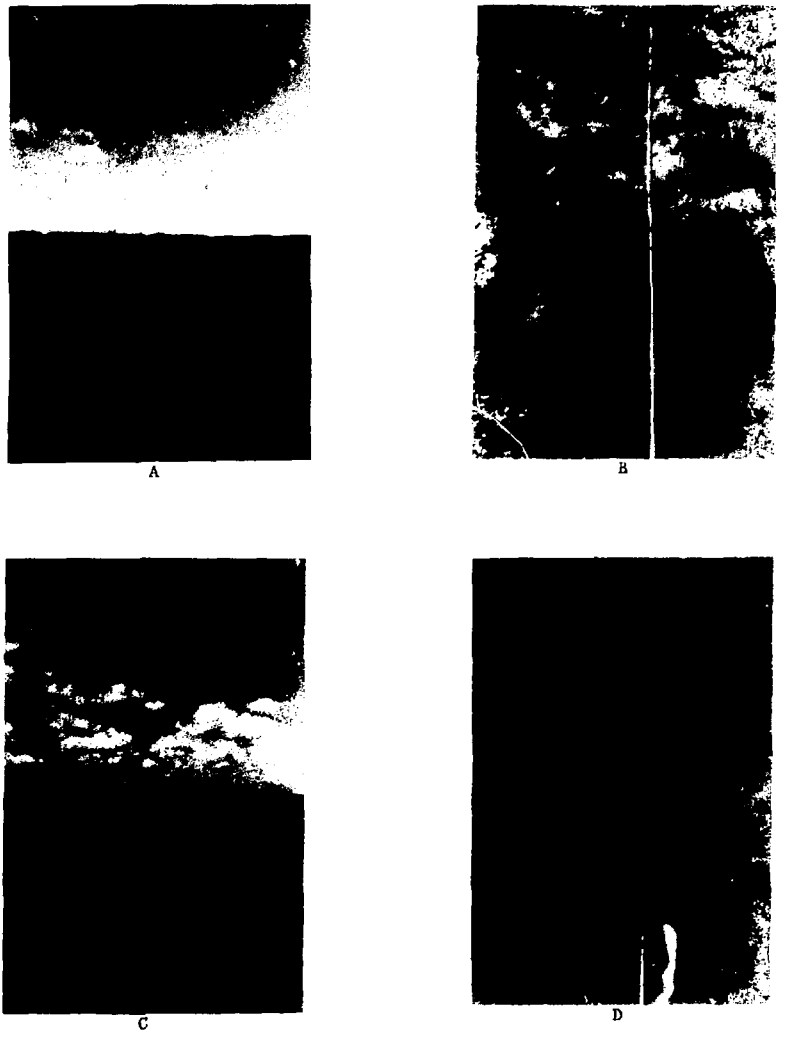


Figure 6.6. Undisturbed Transects 17 (A and B) and 16 (C and D) on the Gnome Site. Location is west-northwest of the Shaft.

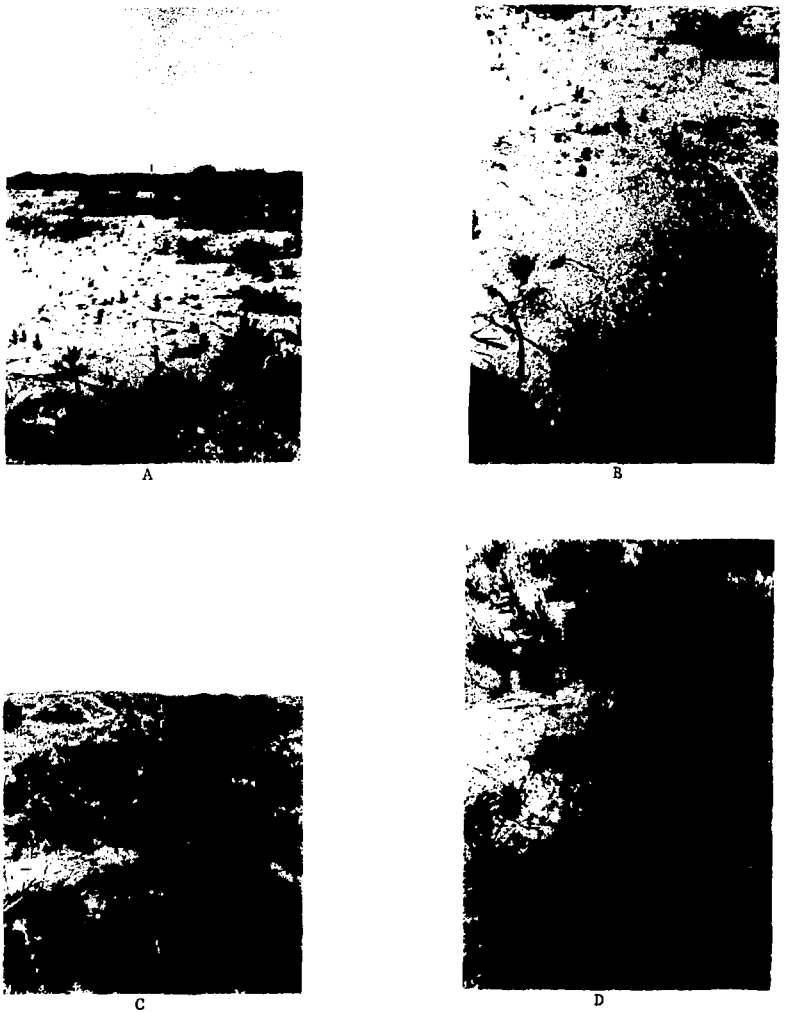


Figure 6.7. The Gnome Site Southwest Pad Was Disturbed in 1959. The caliche base, A and B, has prevented many plants from re-entering. C and D are the undisturbed comparison.

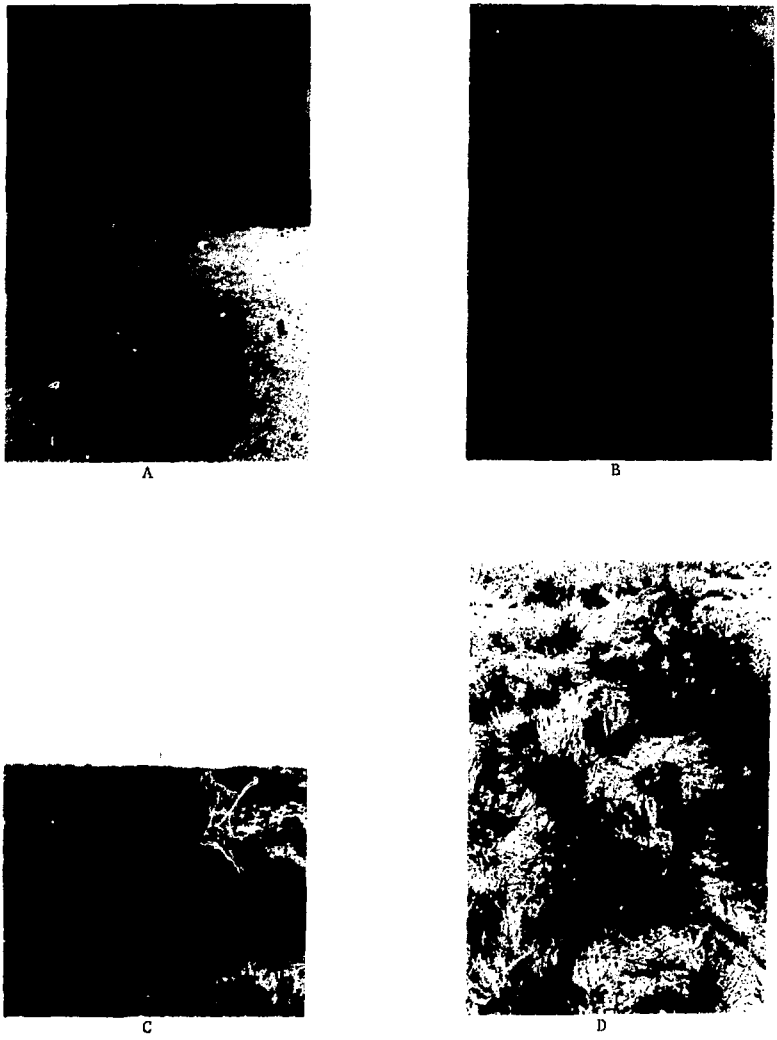
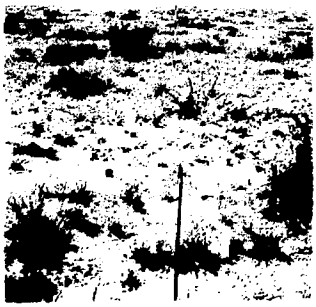
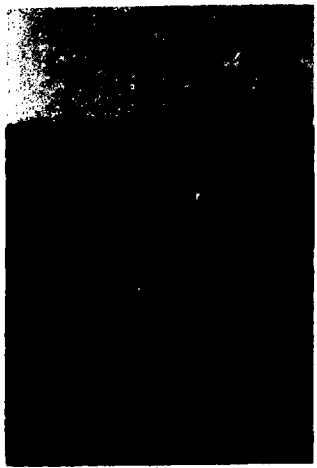


Figure 6.8. The south pad on the Gnome Site was disturbed in 1963 and is still relatively sterile--A and B--while the comparison C and D has good shrub and grass cover.

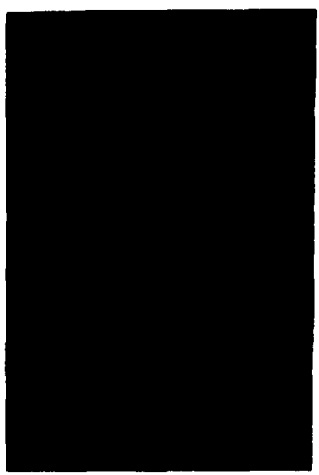


A



B

C



D

Figure 6.9. The 1977 pad (B) on the Gnome Site had no plants present while the area to the south (A, C, and D) has a sparse stand of shrubs and grass.

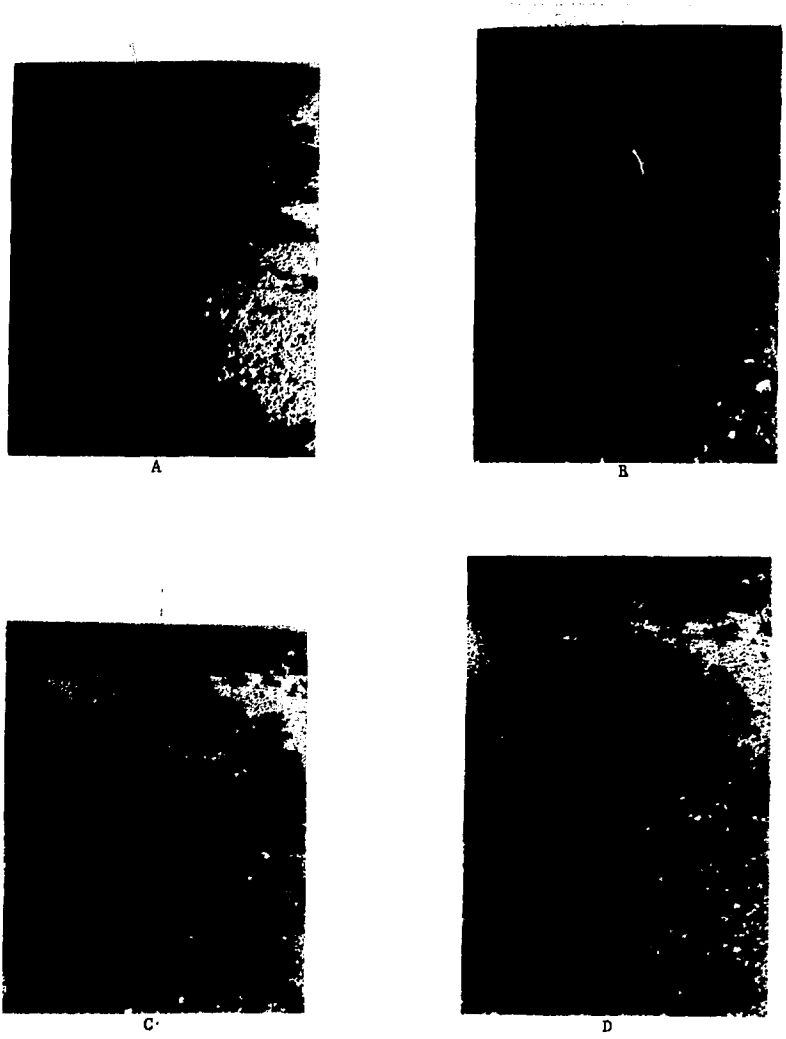


Figure 6.10. Inside the Nash Draw Exclosure (A and B) bush muhly is the dominant grass while outside the fence (C and D), grass cover was low.

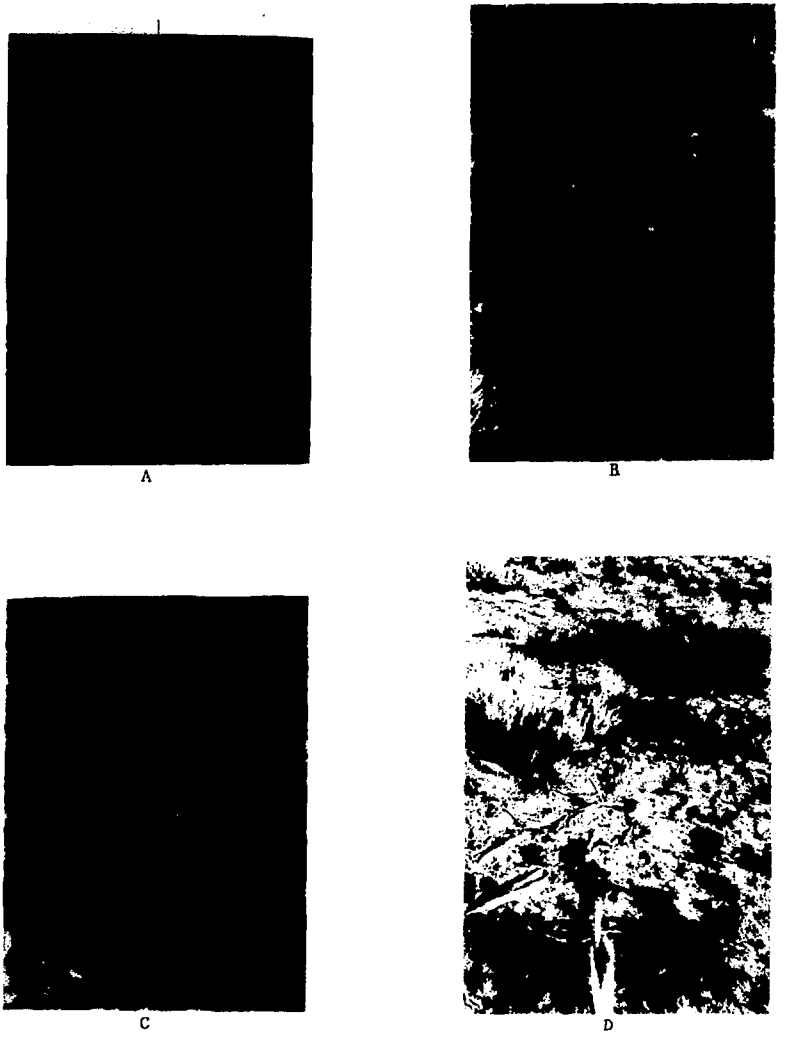


Figure 6.11. The Red Tank Exclosure (A and B) is beginning to support a healthy grass turf while grazing and trampling damage are destroying vegetation outside (C and D) the exclosure.

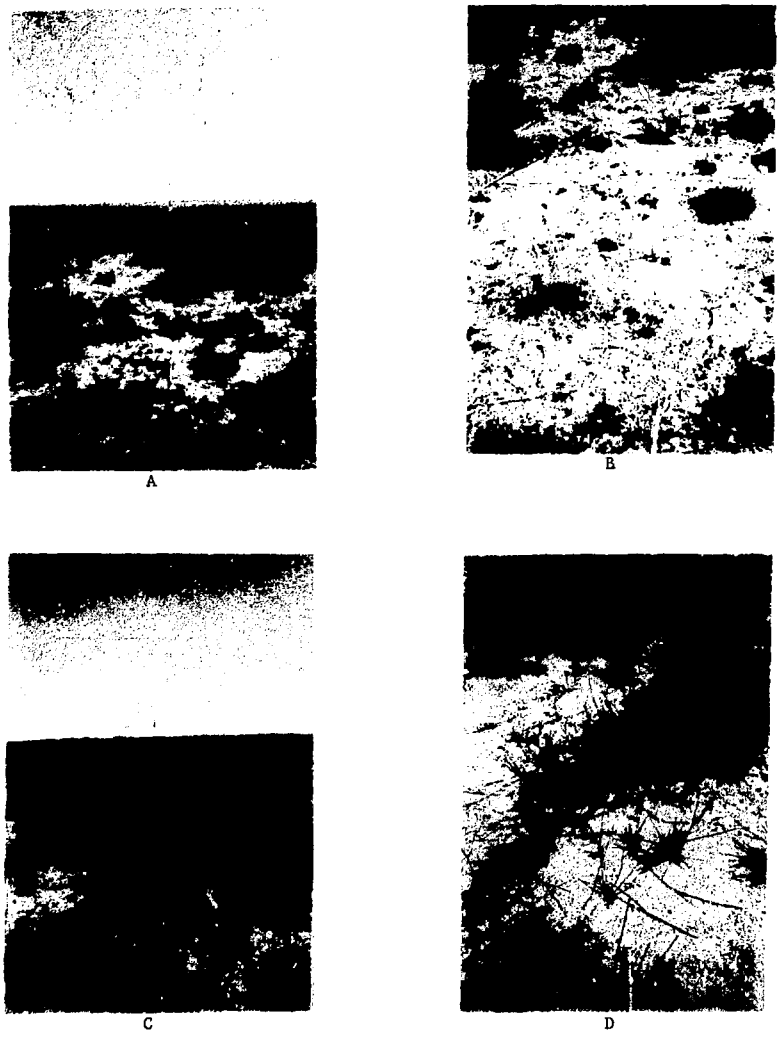
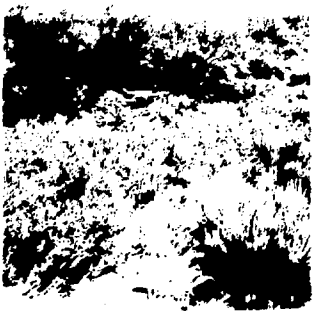


Figure 6.12. The section 15 exclosure-to-be (A and B) is in poor range condition while the section 20 exclosure to be (C and D) supports a good stand of dropseed.

A

B



C

D

Figure 6.13. The mesquite-bird areas (A, B, C, and D) show a sparse herb layer while the mesquite-oak canopy is variable on this hummocky topography.

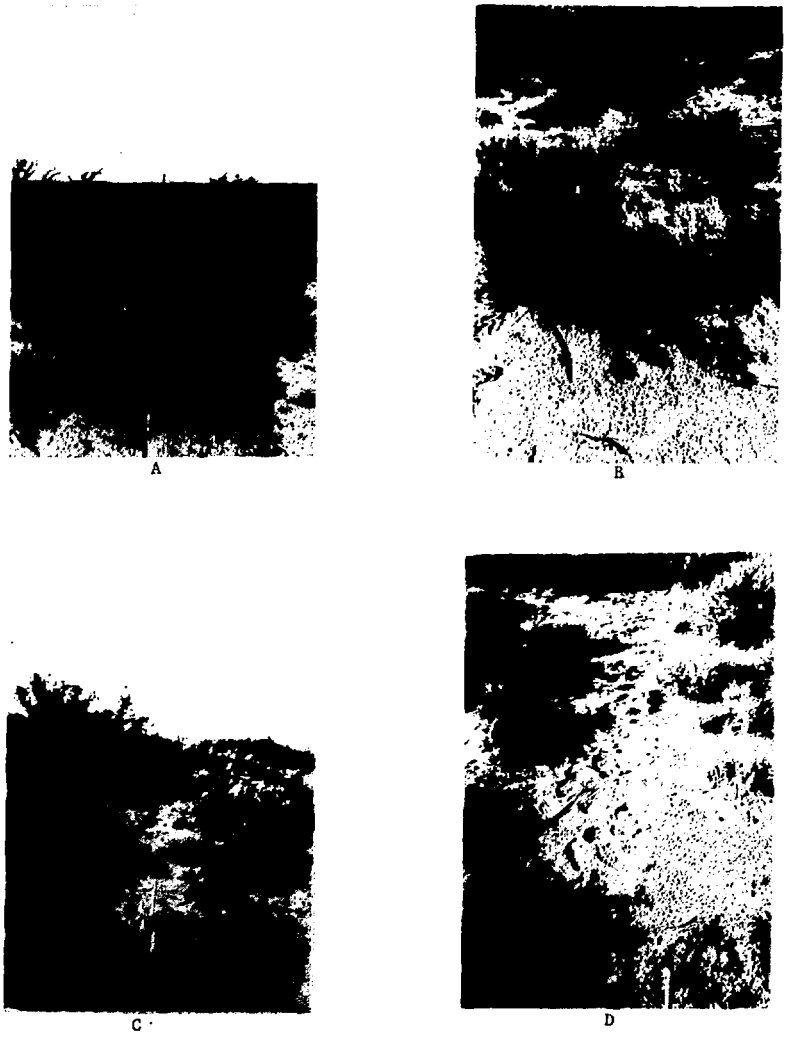


Figure 6.14. Inside the section 28 exclosure (A and B), a contrast in vegetation is obvious when compared to the campground area (C and D) on the WIPP site.

Table 6.1. Legal Description for Permanent Study Sites

Existing Exclosures	Location
Two hectare	SE 1/4 Sec 28 T22S R31E
Two hectare	N 1/2 NW 1/4 NE 1/4 Sec 20 T22S R31E
Red Tank	NW 1/4 NW 1/4 Sec 31 T22S R32E
Nash Draw	SE 1/4 Sec 3 T23S R30E
Highway	E 1/2 NW 1/4 Sec 20 T23S R31E
Exclosures-To-Be-Constructed	
(East)	S 1/2 SE 1/4 SW 1/4 Sec 15 T22S R31E
(West)	N 1/2 SW 1/4 SW 1/4 Sec 20 T22S R31E
Bird Transect Areas	
Oak	W 1/2 NW 1/4 NE 1/4 Sec 27 T22S R31E
Mesquite (east)	SW 1/4 SE 1/4 Sec 33 T22S R31E
Mesquite (west)	S 1/2 NE 1/4 Sec 5 T23S R31E
Creosotebush	NW 1/4 Sec 2 T23S R30E
Mesa	Sec 9 T22S R32E
Camp Area	E 1/4 Sec 28 T22S R31E
James Ranch Dunes	SW 1/4 SE 1/4 Sec 5 T23S R31E
Gnome Sites	
1960's Nuclear Test Area	Sec 34 T23S R30E

Table 6.2. Averaged canopy coverage (C) and density (D) of plants found on the Gnome Site Contaminated Waste Dump where soil had been added.

Species	Transect 1 C	Transect 1 D	Transect 2 C	Transect 2 D	Transect 83 C	Transect 83 D	Average Cover	Average Density	Frequency Percent
Aristida purpurea	0.30	0.10	...	...	...	...	0.10	0.03	2
Cenchrus incertus	0.01	0.10	...	...	...	...	0.07	0.03	2
Eragrostis curtipedicellata	0.05	0.10	0.60	0.70	...	...	0.21	0.27	8
Sporobolus cryptandrus	23.50	8.90	12.50	4.40	24.00	5.60	20.00	6.30	60
Leptoloma cognatum	...	...	...	...	0.90	0.60	0.30	0.20	4
Paspalum setaceum	1.20	0.20	0.20	0.20	...	...	0.47	0.13	6
Setaria macrostachya	0.45	0.20	0.60	0.30	1.10	0.20	0.72	0.23	12
Chloris cucullata	...	...	0.03	0.10	...	...	0.01	0.03	2
Erioneuron pulchellum	...	...	...	...	0.10	0.10	0.03	0.03	2
Eragrostis sessilispica	...	...	...	...	0.20	0.10	0.07	0.03	2
Dithyrea wislizenii	...	...	0.10	0.10	0.40	0.10	0.17	0.07	4
Eriogonum annuum	0.03	0.10	0.01	0.10	0.25	0.60	0.10	0.27	12
Mentzelia sp.	...	...	...	...	1.30	0.20	0.43	0.07	4
Phyllanthus sp.	...	...	0.10	0.10	...	...	0.03	0.03	2
Senecio spartoides	0.08	0.30	0.15	0.30	...	...	0.08	0.20	10
Phacelia sp.	0.53	0.80	0.85	1.80	...	...	0.45	0.87	14
Selloa sp.	0.80	1.00	...	...	...	...	0.27	0.33	2
Machaeranthera tanacetifolia	...	...	0.30	0.10	...	...	0.10	0.03	4
Sida physocalyx	...	...	0.03	0.10	...	...	0.01	0.03	2
Croton dioicus	...	...	...	...	1.00	0.20	1.00	0.07	4
Macta sp.	...	...	...	...	0.20	0.10	0.07	0.03	2
Litter	32.70	...	50.80	...	64.00	...	49.17	...	

Table 6.3. Average canopy coverage (C) and density (D) of plants found on the Gnome Site Contaminated Waste Dump scraped area.

Species	Transect 3 C	Transect 3 D	Transect 4 C	Transect 4 D	Transect 84 C	Transect 84 D	Average Cover	Average Density	Frequency Percent
Aristida purpurea	3.10	4.40	1.00	0.50	...	...	1.37	1.63	11
Bouteloua eriopoda	...	...	0.60	1.00	...	...	0.20	0.33	2
Cenchrus incertus	...	...	...	...	0.20	0.10	0.07	0.03	2
Sporobolus cryptandrus	2.45	2.20	0.55	0.80	...	...	1.00	1.00	20
Paspalum sp.	3.55	1.50	0.15	0.30	...	...	1.23	0.60	6
Sporobolus giganteus	...	...	1.80	0.50	...	...	0.60	0.17	4
Aristida divaricata	0.65	0.30	...	...	...	...	0.22	0.10	6
Aristida longiseta	...	...	1.90	0.40	...	...	0.63	0.13	6
Aristida sp.	...	...	...	...	12.60	2.50	4.20	0.83	20
Muhlenbergia porteri	...	...	...	...	1.50	0.20	0.50	0.07	2
Eragrostis sessilispica	...	...	...	...	0.10	0.10	0.03	0.03	2
Panicum obtusum	...	...	...	...	0.01	...	0.01	...	
Croton sp.	...	...	1.00	0.50	...	...	0.33	0.17	8
Euphorbia missurica	1.20	1.50	...	...	...	...	0.40	0.50	4
Aristida wrightii	...	...	1.80	0.30	...	...	0.60	0.10	6
Melampodium leucanthum	4.30	6.20	4.90	6.10	5.80	3.70	5.00	5.33	58
Solanum sp.	0.05	0.30	...	...	0.15	0.20	0.07	0.17	10
Euphorbia sp.	...	...	0.30	0.60	...	...	0.10	0.20	4
Euphorbia fendleri	...	...	...	...	1.00	3.40	0.33	1.13	6
Gutierrezia sarothrae	4.80	0.20	1.60	0.40	0.80	0.20	2.40	0.27	12
Litter	13.1	...	12.90	...	24.80	...	16.93	...	

Table 6.4. Average canopy coverage (C) and density (D) of plants found on the Gnome Site Contaminated Waste Dump scraped area.

Species	Transect 5 C	Transect 5 D	Transect 6 C	Transect 6 D	Transect 85 C	Transect 85 D	Average Cover	Average Density	Frequency Percent
Aristida purpurea	...	...	2.60	0.40	...	...	0.87	0.13	13
Bouteloua eriopoda	30.60	10.20	8.80	3.70	30.00	5.70	23.13	6.53	90
Leptoloma cognatum	...	...	0.90	0.20	...	...	0.30	0.07	7
Sporobolus cryptandrus	1.40	0.50	2.15	1.00	...	...	1.18	0.50	30
Sporobolus giganteus	0.70	0.40	...	...	...	...	0.23	0.13	3
Paspalum sp.	1.83	0.80	6.00	1.30	...	...	2.61	0.70	37
Aristida sp.	...	...	...	...	4.10	0.90	1.37	0.30	7
Sporobolus sp.	...	...	...	...	1.00	0.20	0.33	0.07	3
Panicum obtusum	...	...	...	...	2.40	0.20	0.80	0.07	7
Croton sp.	0.60	0.20	0.60	0.20	...	...	0.40	0.13	13
Eriogonum annuum	0.03	0.10	...	...	...	...	0.01	0.03	3
Heleanthus sp.	...	...	0.10	1.20	...	...	0.03	0.40	3
Melampodium leucanthum	1.65	0.90	4.30	1.70	2.20	1.00	2.72	1.20	50
Senecio spartoides	0.03	0.10	...	...	...	...	0.01	0.03	3
Solanum sp.	1.15	1.20	1.20	3.00	1.80	1.70	1.38	1.97	53
Lesquerella sp.	0.05	0.20	...	...	...	...	0.02	0.07	3
Zinnia grandiflora	0.07	0.10	...	...	...	...	0.02	0.03	3
Mirabilis sp.	...	...	0.30	...	...	...	0.10	...	0
Krameria parvifolia	...	...	...	...	1.50	0.50	0.50	0.17	3
Croton dioicus	...	...	...	...	2.90	0.40	0.97	0.13	10
Chrysothamnus pulchellus	...	...	1.20	0.10	...	...	0.40	0.03	3
Prosopis glandulosa	...	...	1.0	...	...	...	0.03	...	0
Gutierrezia sarothrae	1.90	0.70	...	...	0.50	0.10	0.80	0.27	10
Mimosa sp.	1.10	...	...	...	...	...	0.37	...	0
Yucca sp.	1.10	...	4.50	0.40	0.01	...	1.87	0.13	3
Ephedra sp.	0.50	0.20	4.00	0.40	2.80	0.20	2.43	0.27	13
Machaerinotera sp.	...	...	0.10	0.20	...	...	0.03	0.07	7
Litter	23.50	...	41.60	...	69.80	...	44.97	...	0

Table 6.5. Averaged canopy cover (C) and density (D) of plants found on the Gnome Site Salvage Yard scraped site.

Species	Transect 7 C	Transect 7 D	Transect 8 C	Transect 8 D	Transect 86 C	Transect 86 D	Average Cover	Average Density	Frequency Percent
Aristida purpurea	2.60	1.70	1.70	1.30	2.50	2.70	2.27	1.90	60
Sporobolus cryptandrus	0.30	0.10	0.60	0.50	...	...	0.30	0.20	17
Aristida divaricata	...	...	0.90	0.60	...	...	0.30	0.20	10
Aristida longiseta	0.60	0.70	...	...	...	...	0.20	0.23	7
Erioneuron pulchellum	0.10	0.10	...	...	...	...	0.03	0.03	3
Unknown	...	...	0.85	2.30	...	...	0.28	0.77	17
Sporobolus sp.	...	...	...	...	1.00	0.20	0.30	0.07	7
Croton sp.	0.75	0.20	0.49	0.80	2.00	0.40	1.08	0.47	30
Eriogonum annuum	0.01	0.10	...	...	...	...	0.01	0.03	3
Melampodium leucanthum	6.00	4.80	7.75	6.20	13.90	2.70	9.22	4.57	93
Senecio spartoides	0.01	0.10	...	...	...	...	0.01	0.03	3
Solanum sp.	...	...	0.17	0.60	0.10	0.20	0.09	0.27	17
Euphorbia sp.	0.33	0.70	...	...	1.85	0.70	0.73	0.47	20
Linum sp.	...	...	0.01	0.30	0.40	0.30	0.14	0.20	13
Euphorbia fendleri	...	...	2.30	4.00	...	...	0.77	0.13	10
Dalea sp.	...	...	...	...	0.50	0.10	0.17	0.03	3
Gutierrezia sarothrae	3.90	4.90	1.40	1.20	...	...	1.77	2.03	50
Yucca sp.	...	...	2.50	0.10	...	...	0.83	0.03	3
Krameria lanceolata	...	...	0.60	0.10	...	...	0.20	0.03	3
Litter	8.40	...	4.60	...	15.60	...	9.53	...	0

Table 6.6. Averaged canopy coverage (C) and density (D) of plants found on the Gnome Site Salvage Yard undisturbed comparison.

Species	Transect 9 C	Transect 9 D	Transect 10 C	Transect 10 D	Transect 87 C	Transect 87 D	Average Cover	Average Density	Frequency Percent
Aristida purpurea	0.60	0.30	0.30	0.20	...	...	0.30	0.17	7
Bouteloua eriopoda	21.80	11.40	30.40	13.40	34.40	9.30	28.87	11.37	100
Cenchrus incertus	...	...	...	...	0.20	0.10	0.07	0.03	3
Sporobolus cryptandrus	0.90	0.40	1.00	0.40	0.30	0.10	0.73	0.30	17
Sporobolus giganteus	0.10	0.10	...	...	...	...	0.03	0.03	3
Chloris cucullata	...	...	0.10	0.10	...	...	0.03	0.03	3
Aristida longiseta	...	...	0.40	0.10	...	...	0.13	0.03	3
Aristida wrightii	...	...	...	...	0.80	0.10	0.27	0.03	10
Erioneuron pulchellum	2.00	1.00	...	...	...	...	0.07	0.33	
Cyperus sp.	...	...	0.10	0.10	...	...	0.03	0.03	3
Panicum obtusum	...	...	...	...	0.60	0.40	0.20	0.13	7
Croton sp.	0.20	0.10	4.10	0.60	0.40	0.10	1.57	0.27	20
Melampodium leucanthum	2.37	1.80	0.95	1.10	1.20	0.70	1.51	1.20	50
Mentzelia sp.	...	...	...	...	0.10	0.10	0.03	0.03	3
Machaeranthera tanacetifolia	...	...	0.20	0.10	...	...	0.07	0.03	3
Solanum sp.	0.10	0.30	1.30	1.90	...	...	0.47	0.73	10
Euphorbia sp.	0.10	0.10	...	...	...	...	0.03	0.03	3
Euphorbia fendleri	...	...	0.01	0.20	...	...	0.01	0.07	3
Krameria parvifolia	2.80	0.70	...	...	0.60	0.60	1.13	0.43	20
Pectis sp.	...	...	0.01	0.10	...	...	0.01	0.03	3
Psilostrophe sp.	...	...	0.40	0.20	...	...	0.13	0.07	3
Gutierrezia dracunculoides	...	...	...	...	1.40	0.70	0.47	0.23	3
Gutierrezia sarothrae	2.40	0.60	1.10	4.00	...	...	1.17	1.53	21
Yucca sp.	6.70	0.20	...	...	12.00	0.10	6.23	0.10	20
Ephedra sp.	1.00	0.40	...	...	...	...	0.30	0.13	7
Krameria sp.	...	...	0.30	...	...	...	0.10	...	3
Opuntia sp.	...	...	...	...	0.10	0.10	0.03	0.03	3
Litter	22.00	...	22.80	...	47.10	...	30.63	...	

Table 6.7. Averaged canopy cover (C) and density (D) of plants sampled on the Gnome Site Warehouse disturbed (pad) site.

Species	Transect 11 C	Transect 11 D	Transect 12 C	Transect 12 D	Transect 88 C	Transect 88 D	Average Cover	Average Density	Frequency Percent
Aristida purpurea	2.50	0.20	...	...	...	...	0.83	0.07	3
Eragrostis curtipedicellata	0.60	0.10	...	...	...	...	0.20	0.03	3
Sporobolus cryptandrus	0.10	0.10	...	...	...	...	0.03	0.03	3
Sporobolus giganteus	0.60	0.10	...	...	...	...	0.20	0.03	3
Setaria macrostachya	0.60	0.20	...	...	...	...	0.20	0.07	7
Aristida wrightii	1.00	0.20	...	...	...	...	0.33	0.07	3
Erioneuron pulchellum	0.43	1.10	...	...	0.80	1.00	0.41	0.70	17
Bothriochloa sp.	1.60	0.20	4.60	0.50	2.10	0.50	2.77	0.40	27
Eragrostis sp.	...	...	0.40	0.30	...	...	0.13	0.10	7
Aristida sp.	...	...	...	...	5.30	1.20	1.77	0.40	20
Dithyrea wislizenii	...	...	...	...	0.10	0.10	0.03	0.03	3
Eriogonum annuum	0.46	1.40	0.32	1.00	...	...	0.26	0.80	33
Euphorbia missurica	...	...	...	...	0.10	0.10	0.03	0.03	3
Heterotheca latifolia	...	...	2.37	1.90	1.20	0.20	1.19	0.70	27
Melampodium leucanthum	0.01	0.10	...	...	...	...	0.01	0.03	3
Phacelia sp.	0.10	0.10	...	...	...	...	0.03	0.03	7
Solanum sp.	0.10	0.10	...	...	...	...	0.03	0.03	3
Heterotheca villosa	.05	4.80	...	...	...	...	0.68	1.60	17
Conyza canadensis	2.00	2.20	...	...	...	...	0.70	0.73	17
Solanum elaeagnifolium	...	...	0.60	0.30	...	...	0.20	0.10	7
Conyza sp.	...	...	2.20	4.20	3.00	1.10	1.73	1.77	30
Erigeron sp.	...	...	...	...	2.60	0.60	0.87	0.20	10
Artemisia filifolia	3.10	0.40	...	...	1.00	...	1.37	0.13	10
Gutierrezia sarothrae	...	...	4.70	0.10	1.20	0.20	1.97	0.10	7
Houstonia sp	0.05	0.10	...	...	...	...	0.02	0.03	3
Psilostachia sp.	0.01	0.10	...	...	...	...	0.01	0.03	3
Litter	17.30	...	8.20	...	36.90	...	20.80	...	...

Table 6.8. Averaged canopy coverage (C) and density (D) of plants found on the Gnome Site Warehouse undisturbed comparison site.

Species	Transect 13 C	Transect 13 D	Transect 14 C	Transect 14 D	Transect 89 C	Transect 89 D	Average Cover	Average Density	Frequency Percent
Bouteloua eriopoda	...	...	1.00	0.50	...	...	0.33	0.17	3
Cenchrus incertus	...	...	...	...	0.10	0.10	0.03	0.03	3
Eragrostis curtipedicallata	...	...	0.30	0.20	...	...	0.10	0.07	7
Monroa squarrosa	...	...	...	...	0.10	0.10	0.03	0.03	3
Sporobolus cryptandrus	11.40	2.10	10.50	2.50	...	...	7.30	1.53	60
Setaria macrostachya	0.60	0.40	...	...	0.40	0.10	0.33	0.17	7
Aristida divaricata	...	...	0.50	0.10	...	...	0.17	0.03	3
Erioneuron pulchellum	...	...	...	...	0.20	0.10	0.07	0.03	3
Aristida sp.	...	...	...	...	0.70	0.40	0.23	0.13	7
Sporobolus sp.	...	...	...	...	11.10	3.50	3.70	1.17	27
Croton sp.	2.00	0.30	...	...	...	...	0.07	0.10	10
Dithyrea wislizenii	0.10	0.20	...	...	0.10	0.10	0.07	0.10	7
Eriogonum annuum	...	...	0.65	0.90	...	...	0.22	0.30	10
Heterotheca latifolia	...	...	2.00	1.10	...	...	0.70	0.37	13
Melampodium leucanthum	...	...	...	...	0.70	0.10	0.23	0.03	3
Mentzelia sp.	...	...	0.20	0.30	...	...	0.07	0.10	10
Phyllanthus sp.	...	...	...	...	0.20	0.10	0.07	0.03	3
Solanum sp.	...	...	...	...	0.55	0.70	0.18	0.23	20
Houstonia sp	0.10	0.10	...	...	...	...	0.03	0.03	3
Conyza sp.	...	...	...	...	0.10	0.10	0.03	0.03	3
Erigeron sp.	0.45	0.30	4.40	8.20	0.20	0.30	1.68	2.93	40
Erogostis sp.	...	...	...	...	0.50	0.30	0.17	0.10	27
Artemisia filifolia	10.35	0.80	8.50	0.10	5.00	0.50	7.95	0.47	30
Quercus havardii	10.10	0.70	4.70	0.40	6.90	1.10	7.23	0.73	10
Dalea sp.	...	...	0.30	0.10	...	...	0.10	0.03	3
Gutierrezia dracunculoides	...	...	...	...	0.50	0.10	0.17	0.03	3
Caesalpinia sp.	...	...	...	...	0.50	0.30	0.17	0.10	3
Litter	54.40	...	41.60	...	31.00	...	42.33	...	...

Table 6.9. Averaged canopy cover (C) and density (D) of plants found west-northwest of the Gnome Site Shaft.

Species	Transect 17 C	Transect 17 D	Transect 18 C	Transect 18 D	Transect 82 C	Transect 82 D	Average Cover	Average Density	Frequency Percent
Aristida purpurea	...	...	1.70	0.50	...	...	0.57	0.17	10
Bouteloua eriopoda	20.10	6.80	0.35	0.60	15.40	5.20	11.95	4.20	57
Cenchrus incertus	...	...	...	...	0.90	0.40	0.30	0.13	10
Eragrostis curtipedicellata	0.20	0.10	2.40	1.10	...	...	0.87	0.40	10
Sporobolus cryptandrus	5.60	2.70	6.10	2.50	2.00	1.50	4.57	2.23	63
Chloris cucullata	0.30	0.30	0.95	0.50	...	...	0.42	0.27	7
Aristida divaricata	1.00	0.20	...	...	...	...	0.33	0.07	7
Aristida wrightii	0.70	0.30	0.90	0.20	...	...	0.53	0.17	13
Aristida sp.	...	...	...	...	2.30	0.90	0.77	0.30	3
Cyperus sp.	0.10	0.10	...	...	...	...	0.03	0.03	3
Eragrostis sessilispica	...	...	...	...	1.40	0.70	0.47	0.23	7
Aphanosetephus sp.	5.50	13.70	2.95	15.60	2.40	2.30	3.62	10.53	80
Croton sp.	0.50	0.10	1.30	0.10	2.20	0.30	1.33	0.17	13
Dithyrea wislizenii	0.02	0.20	...	...	...	...	0.01	0.07	7
Eriogonum annuum	...	...	0.03	0.10	0.10	0.10	0.04	0.07	7
Melampodium leucanthum	2.30	1.50	7.70	4.40	4.20	1.90	4.73	2.60	50
Solanum sp.	1.92	2.80	0.60	1.30	...	...	0.84	1.37	30
Heterotheca villosa	...	...	0.05	0.60	...	...	0.02	0.20	...
Uramaria sp.	13.00	0.30	...	...	...	...	0.43	0.10	7
Hoffmanseggia jameseii	...	...	0.10	0.10	...	...	0.03	0.03	3
Prosopis glandulosa	0.80	0.10	0.10	...	...	...	0.30	0.03	7
Quercus havardii	...	...	0.60	0.10	6.50	0.60	2.37	0.23	10
Gutierrezia sarothrae	0.10	0.20	2.20	1.00	4.50	0.10	2.27	0.43	17
Yucca sp.	6.00	0.10	...	...	2.50	0.20	2.83	0.10	10
Unknown	0.01	0.10	...	...	...	...	0.01	0.03	3
Litter	34.80	...	23.70	...	60.80	...	39.77	...	...

Table 6.10. Averaged canopy cover (C) and density (D) of plants recorded west-northwest of the Gnome Site Shaft.

Species	Transect 15 C	Transect 15 D	Transect 16 C	Transect 16 D	Transect 81 C	Transect 81 D	Average Cover	Average Density	Frequency Percent
Aristida purpurea	3.60	0.80	...	...	...	...	1.20	0.27	20
Bouteloua eriopoda	1.55	0.80	4.00	1.50	...	...	1.85	0.77	13
Cenchrus incertus	...	...	...	...	0.60	0.20	0.20	0.07	3
Eragrostis curtipedicellata	3.20	1.40	0.70	0.40	...	...	1.30	0.60	13
Sporobolus cryptandrus	2.90	2.10	4.55	2.20	6.50	1.60	4.65	1.97	57
Setaria macrostachya	0.40	...	...	...	0.50	0.10	0.30	0.03	7
Chloris cucullata	...	...	0.60	0.50	0.50	0.30	0.37	0.27	10
Aristida divaricata	...	...	...	...	1.40	0.70	0.47	0.23	7
Aristida wrightii	...	...	0.10	0.10	...	...	0.03	0.03	3
Eragrostis sp.	...	...	0.50	0.10	...	...	0.17	0.03	13
Aristida sp.	0.10	0.10	...	...	...	...	0.03	0.03	3
Cyperus sp.	...	...	0.40	0.30	...	...	0.13	0.10	7
Muhlenbergia porteri	...	...	...	...	1.70	2.00	0.57	0.07	7
Eragrostis sessilispica	...	...	...	...	3.00	1.10	0.10	0.37	10
Aphanosetephus sp.	1.30	4.40	2.60	6.90	4.50	4.80	2.80	5.37	63
Croton sp.	1.40	0.50	5.50	0.30	2.90	0.60	3.27	0.47	23
Dithyrea wislizenii	0.10	0.20	...	...	0.05	0.10	0.05	0.10	10
Melampodium leucanthum	2.40	0.80	3.60	1.80	0.60	0.20	2.20	0.93	23
Mentzelia sp.	0.10	0.10	...	...	...	...	0.03	0.03	3
Mirabilis sp.	...	...	1.80	1.00	0.45	0.70	0.75	0.57	...
Heterotheca villosa	0.20	0.30	...	...	...	...	0.07	0.10	7
Senecio sp.	...	...	1.50	0.10	...	...	0.50	0.03	3
Chrysothamnus pulchellus	...	...	...	...	1.40	0.20	0.47	0.07	7
Gutierrezia sarothrae	17.20	2.20	9.80	0.70	...	...	9.00	0.97	50
Yucca sp.	1.00	1.10	4.50	0.20	5.30	0.20	3.60	0.50	26
Litter	31.80	...	37.00	...	58.30	...	42.37	...	...

Table 6.11. Averaged canopy cover (C) and density (D) of plants found on the Gnome Site Southwest pad.

Species	Transect 19 C	Transect 19 D	Transect 20 C	Transect 20 D	Transect 77 C	Transect 77 D	Average Cover	Average Density	Frequency Percent
Aristida purpurea	1.50	0.40	...	...	...	...	0.50	0.13	10
Sporobolus cryptandrus	0.70	0.20	...	...	0.40	0.20	0.37	0.13	7
Sporobolus giganteus	0.50	0.10	...	...	...	...	0.17	0.03	3
Setaria macrostachya	1.20	0.30	...	...	0.55	0.20	0.58	0.17	13
Aristida wrightii	...	...	0.60	0.10	...	...	0.20	0.03	3
Erioneuron pulchellum	0.70	1.00	...	...	1.80	2.10	0.83	1.03	60
Unknown	...	...	0.01	0.10	...	...	0.01	0.03	3
Eragrostis sp.	...	...	2.50	3.00	...	...	0.83	1.00	...
Aristida sp.	...	...	0.40	0.10	2.00	0.50	0.80	0.20	10
Heterotheca latifolia	...	...	...	...	3.00	0.60	1.00	0.20	20
Mentzelia sp.	...	...	...	...	0.05	0.10	0.02	0.03	3
Lesquerella sp.	0.65	0.40	...	...	...	...	0.22	0.13	20
Heterotheca villosa	0.28	0.60	0.30	0.70	...	...	0.19	0.43	37
Senecio sp.	0.86	0.30	...	...	...	...	0.29	0.10	10
Hymenopappus sp.	...	...	0.30	0.30	0.20	0.10	0.17	0.13	13
Dyssodia sp.	...	...	0.05	0.10	...	...	0.02	0.03	3
Artemisia filifolia	...	...	...	...	0.05	0.40	0.02	0.13	3
Gutierrezia sarothrae	...	...	0.50	0.20	...	...	0.17	0.07	7
Litter	22.05	...	6.50	...	0.90	...	9.82	...	...

Table 6.12. Average canopy cover (C) and density (D) of plants found on the undisturbed site at the southwest pad on the Gnome Site.

Species	Transect 21 C	Transect 21 D	Transect 22 C	Transect 22 D	Transect 78 C	Transect 78 D	Average Cover	Average Density	Frequency Percent
Bouteloua eriopoda	...	...	...	...	4.55	0.80	1.52	0.27	10
Brachiaria ciliatissima	1.40	1.80	0.40	0.90	...	...	0.60	0.90	13
Cenchrus incertus	0.80	0.40	...	...	1.30	0.20	0.70	0.20	17
Eragrostis curtipedicellata	0.50	0.10	...	...	...	...	0.17	0.03	3
Leptoloma cognatum	1.90	1.00	...	...	0.70	0.50	0.87	0.20	13
Sporobolus cryptandrus	5.40	2.90	13.30	4.90	8.60	1.30	9.10	3.03	90
Setaria macrostachya	0.90	0.20	...	...	1.00	0.10	0.63	0.10	10
Chloris cucullata	1.60	0.50	1.40	0.40	...	...	1.00	0.20	17
Aristida divaricata	0.50	0.10	2.50	0.30	...	...	1.00	0.13	10
Aristida wrightii	0.70	0.20	1.00	0.20	...	...	0.57	0.13	7
Unknown	...	...	0.60	0.10	...	...	0.20	0.03	3
Aristida sp.	...	...	...	...	1.40	0.30	0.47	0.10	7
Eragrostis sessilispica	...	...	...	...	2.1p	0.30	0.70	0.10	7
Ambrosia psilostachya	0.40	0.10	...	...	...	...	0.13	0.03	3
Croton sp.	...	...	0.50	0.10	...	...	0.17	0.03	3
Eriogonum annuum	0.05	0.10	0.20	0.30	0.12	0.20	0.12	0.20	53
Heterotheca latifolia	...	...	...	...	0.35	0.30	0.12	0.10	10
Heterotheca villosa	0.76	0.40	0.30	0.30	...	...	0.35	0.23	23
Erigeron sp.	2.50	1.90	7.00	10.60	0.10	0.10	3.23	4.20	50
Artemisia [illegible]	...	...	5.00	0.10	0.50	0.30	1.83	0.13	13
Quercus h[illegible]	21.15	1.90	1.90	0.10	19.70	3.40	14.25	1.80	43
Gutierrezia sarothr[illegible]	...	...	1.00	...	...	...	0.03	...	...
Litter	55.90	...	54.00	...	67.20	...	59.03	...	...

Table 6.13. Average canopy cover (C) and density (D) of plants found on south of shaft pad on the Gnome Site.

Species	Transect 23 C	Transect 23 D	Transect 24 C	Transect 24 D	Transect 79 C	Transect 79 D	Average Cover	Average Density	Frequency Percent
Aristida purpurea	...	...	0.10	0.10	...	...	0.03	0.03	3
Unknown	...	...	2.50	0.90	...	...	0.83	0.30	7
Heterotheca leucanthum	...	...	...	...	0.02	0.10	0.01	0.03	3
Artemisia filifolia	...	...	...	...	0.10	...	0.03	...	...
Litter	0.73	...	1.50	...	0.20	...	0.81	...	...

Table 6.14. Canopy cover (C) and density (D) of plant recorded south of the 1977 ERDA 10 pad on the Gnome Site.

Species	Transect 93 C	Transect 93 D	Transect 94 C	Transect 94 D	Transect 95 C	Transect 95 D	Average Cover	Average Density	Frequency Percent
Setaria macrostachya	...	...	0.80	0.20	...	...	0.27	0.27	3
Chloris cucullata	0.60	0.60	0.50	0.10	...	...	0.37	0.23	7
Aristida sp.	4.80	2.30	7.00	2.40	6.80	2.10	6.20	2.27	67
Sporobolus sp.	2.10	0.90	2.50	1.10	4.20	1.60	2.93	1.20	60
Croton sp.	3.60	0.30	0.40	0.10	0.01	0.10	1.34	0.17	17
Dithyrea wislizenii	0.10	0.10	...	...	...	...	0.03	0.03	3
Melampodium leucanthum	10.20	3.90	5.60	2.00	5.60	2.50	7.13	2.80	80
Solanum sp.	0.20	0.20	0.60	0.80	0.45	0.60	0.42	0.53	27
Lesquerella sp.	...	...	0.03	0.10	...	...	0.01	0.03	3
Mirabilis sp.	...	...	0.20	0.10	...	...	0.07	0.03	3
Psilostrophe sp.	0.50	0.10	...	...	...	...	0.17	0.03	3
Senecio sp.	...	...	0.10	0.10	...	...	0.03	0.03	3
Gutierrezia dracunculoides	0.30	0.40	...	...	6.43	0.60	2.24	0.33	23
Artemisia filifolia	...	...	2.20	0.20	...	...	0.73	0.07	3
Chrysothamnus pulchellus	...	...	8.80	0.70	...	...	2.93	0.23	20
Prosopis glandulosa	...	...	1.50	...	...	...	0.50	...	...
Mimosa sp.	...	...	...	...	10.80	0.10	3.60	0.03	7
Yucca sp.	4.00	...	7.50	0.20	2.00	0.10	4.50	0.10	10
Litter	46.80	...	51.90	...	51.00	...	49.90	...	...

Table 6.15. Averaged canopy cover (C) and density (D) of plants found on the Gnome Site undisturbed transects south of the shaft.

Species	Transect 25 C	Transect 25 D	Transect 26 C	Transect 26 D	Transect 80 C	Transect 80 D	Average Cover	Average Density	Frequency Percent
Bouteloua eriopoda	3.90	2.90	...	...	0.50	0.20	1.47	1.03	13
Brachiaria ciliatissima	0.40	0.60	...	...	...	...	0.13	0.20	3
Cenchrus incertus	0.90	0.40	...	...	1.20	0.30	0.70	0.23	17
Leptoloma cognatum	2.60	1.00	...	...	0.30	0.30	0.97	0.43	10
Sporobolus cryptandrus	3.90	1.30	6.10	2.40	11.00	2.10	7.00	1.93	70
Sporobolus giganteus	2.00	1.70	2.70	0.70	...	...	1.57	0.80	20
Setaria macrostachya	...	...	0.40	0.10	...	...	0.13	0.03	3
Chloris cucullata	0.20	0.10	...	...	...	...	0.07	0.03	3
Aristida wrightii	0.50	0.30	...	...	...	...	0.17	0.10	3
Aristida sp.	...	...	0.10	0.10	0.40	0.20	0.17	0.10	7
Muhlenbergia torreyi	...	...	...	...	0.50	0.10	0.02	0.03	3
Sporobolus flexuosus	...	...	...	...	1.60	0.40	0.53	0.13	3
Croton sp.	1.90	0.30	...	...	...	...	0.63	0.10	10
Eriogonum annuum	0.07	0.20	0.90	0.80	0.10	0.20	0.36	0.40	27
Melampodium leucanthum	0.10	0.10	2.50	0.10	0.01	...	0.87	0.07	13
Mentzelia sp.	...	...	0.20	0.10	...	...	0.07	0.03	3
Senecio spartoides	0.05	0.10	...	...	...	...	0.03	0.03	3
Heterotheca villosa	...	...	0.50	0.20	...	...	0.17	0.67	7
Houstonia sp.	3.50	34.50	2.50	13.00	...	...	2.00	15.83	43
Croton dioicus	...	...	...	...	1.40	0.20	0.47	0.67	17
Quercus havardii	9.90	3.80	12.50	1.10	14.10	18.10	12.17	23.00	40
Yucca sp.	...	...	1.30	0.20	2.00	...	1.03	0.07	10
Dalea sp.	...	...	...	...	0.40	0.10	0.13	0.03	3
Artemisia filifolia	...	...	...	...	1.00	0.20	0.33	0.07	7
Prosopis glandulosa	10.00	0.10	...	...	...	...	3.33	0.03	3
Litter	46.70	...	29.50	...	55.50	...	43.90	...	...

Table 6.16. Averaged canopy cover (C) and density (D) of plants recorded on transects inside of the Nash Draw Exclosure.

Species	Transect 57 C	57 D	58 C	58 D	59 C	59 D	60 C	60 D	61 C	61 D	Average Cover	Average Density	Frequency Percent
Bouteloua eriopoda	...	...	...	...	...	...	2.00	0.90	3.50	0.70	0.32	1.10	10
Eragrostis sp.	...	...	...	...	...	...	0.08	0.10	...	...	0.02	0.02	2
Sporobolus cryptandrus	3.40	1.10	0.30	0.20	0.60	0.50	0.05	0.30	2.40	0.60	1.35	0.54	14
Aristida wrightii	...	...	...	...	1.00	0.20	...	...	...	...	0.20	0.04	2
Munroa squarrosa	...	...	...	...	...	...	0.08	0.10	...	...	0.02	0.02	2
Erioneuron pulchellum	...	...	...	...	...	...	...	...	0.30	2.30	0.06	0.46	8
Aristida sp.	...	...	...	...	...	...	2.70	1.00	0.10	0.10	0.56	0.22	10
Muhlenbergia porteri	4.20	0.50	3.70	0.90	20.40	0.70	5.50	0.70	1.50	0.20	7.04	0.60	10
Sporobolus sp.	0.50	0.10	...	...	...	...	...	...	0.20	0.20	0.14	0.06	12
Euphorbia sp.	...	...	...	...	...	...	0.10	0.20	...	...	0.02	0.04	2
Lesquerella sp.	...	...	0.02	0.20	0.10	2.70	0.30	2.30	...	...	0.08	1.04	22
Krameria sp.	...	...	...	...	4.70	0.20	5.10	1.30	4.35	1.40	2.83	0.58	22
Artemisia filifolia	...	...	...	...	8.00	0.20	...	...	...	...	1.60	0.04	2
Prosopis glandulosa	6.70	0.10	6.50	0.00	4.00	0.10	5.00	0.10	...	...	4.44	0.06	6
Gutierrezia sarothrae	11.10	6.40	7.15	4.50	7.10	4.40	7.70	7.00	10.70	12.70	8.75	7.00	90
Larrea tridentata	14.00	0.30	13.60	0.30	15.50	0.20	0.55	0.20	7.30	0.50	10.19	0.30	26
Opuntia sp.	...	...	...	...	...	...	...	...	1.50	0.10	0.30	0.02	2
Condalia sp.	...	...	...	...	...	...	4.00	0.00	4.40	0.10	1.68	0.02	2
Opuntia leptocaulis	...	...	...	...	...	...	...	...	1.00	0.10	0.20	0.02	2
Unknown	...	...	...	...	0.35	0.60	0.20	0.30	0.50	1.00	0.21	0.38	14

Table 6.17. Averaged canopy cover (C) and density (D) of plants recorded on transects outside of the Nash Draw Exclosure.

Species	Transect 62 C	Transect 62 D	Transect 63 C	Transect 63 D	Transect 64 C	Transect 64 D	Transect 65 C	Transect 65 D	Transect 66 C	Transect 66 D	Average Cover	Average Density	Frequency Percent
Sporobolus cryptandrus	3.50	1.30	0.50	0.40	...	...	...	...	0.35	0.30	0.87	0.40	14
Erioneuron pulchellum	...	...	...	...	0.45	2.60	0.50	4.00	...	...	0.19	1.32	26
Muhlenbergia porteri	5.90	0.50	...	...	...	...	0.50	0.10	3.20	0.30	1.92	0.18	12
Aristida sp.	...	...	...	...	1.10	0.70	0.60	0.10	...	...	0.34	0.16	10
Sporobolus sp.	0.20	0.20	...	...	...	...	...	...	...	...	0.04	0.04	2
Croton sp.	0.05	0.10	...	...	...	...	...	...	...	...	0.01	0.02	2
Euphorbia sp.	...	...	...	...	...	...	0.20	0.70	...	...	0.04	0.14	2
Lesquerella sp.	0.05	0.30	0.05	0.10	0.01	0.10	0.18	1.30	0.05	1.00	0.07	0.56	26
Krameria parvifolia	...	...	...	...	8.85	2.10	5.45	1.10	...	...	2.86	0.64	26
Dyssodia sp.	...	...	...	...	0.01	0.10	...	...	...	...	0.01	0.02	2
Cassia sp.	...	...	...	...	...	...	0.01	0.20	...	...	0.01	0.04	4
Croton dioicus	...	...	0.70	0.20	...	...	...	...	...	...	0.14	0.04	2
Unknown	...	...	...	...	...	...	0.05	0.10	...	...	0.01	0.02	2
Prosopis glandulosa	12.80	0.10	0.50	0.00	...	...	...	...	6.50	0.10	3.96	0.04	4
Gutierrezia sarothrae	6.50	3.60	15.70	7.80	8.20	6.20	6.20	5.70	22.50	7.40	11.82	6.04	86
Larrea tridentata	8.50	0.10	8.00	0.00	2.80	0.20	3.10	0.10	24.80	0.30	9.44	0.14	14
Opuntia leptocaulis	...	...	...	...	...	...	0.10	0.10	...	...	0.02	0.02	4
Condalia sp.	...	...	...	...	0.20	0.00	...	...	...	...	0.04	...	0

Table 6.18. Averaged canopy cover (C) and density (D) of plants found along transects inside of the Red Tank WIPP Site Exclosure.

Species	Transect 72		73		74		75		76		Average		Frequency Percent
	C	D	C	D	C	D	C	D	C	D	Cover	Density	
Aristida purpurea	3.40	1.20	...	...	...	...	...	...	14.30	1.60	3.54	0.56	24
Bouteloua hirsuta	...	...	...	...	0.05	0.10	...	...	0.40	0.10	0.09	0.04	4
Cenchrus incertus	0.10	0.10	0.40	0.10	1.50	0.40	0.70	0.20	1.30	0.20	0.80	0.20	16
Leptoloma cognatum	3.10	2.20	8.70	7.00	1.35	1.30	1.00	0.20	1.40	0.70	3.11	2.28	40
Munroa squarrosa	1.10	1.00	1.08	0.80	0.48	0.50	0.25	0.50	1.40	0.70	0.88	0.70	32
Paspalum setaceum	6.90	1.10	1.20	0.20	2.50	0.20	2.30	0.60	0.80	0.10	3.14	0.44	24
Sporobolus cryptandrus	...	...	...	...	...	...	...	...	5.60	1.70	1.12	0.34	16
Setaria macrostachya	...	...	...	...	...	...	...	...	0.70	0.10	0.14	0.06	2
Erioneuron pulchellum	...	...	0.50	0.10	...	...	...	...	...	...	0.10	0.02	2
Aristida sp.	...	...	...	...	10.60	1.50	1.40	0.20	...	...	2.40	0.34	18
Sporobolus sp.	13.50	2.70	5.80	1.50	7.80	2.00	10.20	1.80	...	...	7.46	1.60	66
Commelina erecta	...	...	...	...	...	...	...	...	0.50	0.10	0.10	0.02	2
Dithyrea wislizenii	...	...	...	...	...	...	0.20	0.10	...	...	0.04	0.02	2
Euphorbia missurica	...	...	...	...	1.50	0.00	0.60	0.20	0.50	0.10	0.52	0.06	6
Mentzelia sp.	...	...	...	...	...	...	0.05	0.10	...	...	0.01	0.02	2
Mirabilis sp.	...	...	0.40	0.20	0.20	0.10	...	...	...	...	0.12	0.06	4
Phyllanthus sp.	...	...	0.20	0.20	0.20	0.20	...	...	0.50	0.20	0.18	0.12	12
Senecio spartoides	...	...	0.20	0.10	...	...	...	...	...	...	0.04	0.02	2
Pectis sp.	0.35	0.50	1.80	3.20	3.50	6.50	1.20	0.10	0.55	0.70	1.48	2.20	54
Houstonia sp	...	...	...	...	...	...	0.10	0.20	...	...	0.02	0.04	2
Dalea sp.	...	...	...	...	...	...	0.10	0.10	...	...	0.02	0.02	2
Artemisia filifolia	...	...	0.20	0.10	0.90	0.20	1.00	0.40	3.60	0.40	1.14	0.22	18
Quercus havardii	22.50	1.90	...	...	3.05	0.60	5.70	1.70	14.00	2.40	9.05	1.40	40
Yucca sp.	...	...	...	...	...	...	2.50	0.10	...	...	0.50	0.02	2
Chrysothamnus pulchellus	...	...	...	...	...	...	8.00	0.10	5.00	0.00	2.60	0.02	2
Litter	52.50	0.00	65.90	0.00	41.50	0.00	56.70	0.00	64.30	0.00	56.18	0.00	

Table 6.19. Averaged canopy cover (C) and density (D) of plants found outside the BLM Red Tank Exclosure.

Species	Transect 67		68		69		70		71		Average		Frequency Percent
	C	D	C	D	C	D	C	D	C	D	Cover	Density	
Bouteloua hirsuta	0.10	0.10	...	...	0.70	0.60	0.60	0.20	0.90	0.60	0.46	0.40	16
Eragrostis curtipedicellata	1.50	1.60	...	...	...	...	...	...	...	...	0.30	0.32	4
Cenchrus incertus	0.60	0.70	0.50	0.70	0.30	0.50	1.20	0.20	1.00	0.70	0.72	0.56	28
Leptoloma cognatum	...	...	0.80	0.30	0.80	1.20	1.60	1.80	1.60	1.90	0.96	1.04	26
Munroa squarrosa	0.20	0.10	0.75	1.00	0.20	0.20	0.60	0.60	1.10	1.10	0.57	0.60	14
Paspalum setaceum	0.20	0.20	0.10	0.10	...	...	0.95	0.50	0.80	0.50	0.41	0.26	14
Sporobolus cryptandrus	1.60	1.20	0.90	1.00	1.30	1.50	...	...	...	...	0.76	0.74	22
Sporobolus giganteus	...	...	...	...	1.50	0.30	...	...	...	...	0.30	0.06	6
Aristida sp.	2.60	1.90	1.70	0.70	1.90	1.30	2.40	0.40	0.60	0.30	1.84	0.92	46
Sporobolus sp.	...	...	...	...	...	...	1.85	1.10	0.70	0.40	0.51	0.30	14
Calylophus sp.	...	...	...	...	...	...	0.60	0.10	...	...	0.12	0.02	2
Croton sp.	...	...	11.50	0.40	17.20	1.60	...	...	1.30	0.10	6.04	0.42	24
Dithyrea wislizenii	...	...	...	...	...	...	0.15	0.20	...	...	0.03	0.04	4
Eriogonum annuum	0.30	0.40	0.10	0.10	0.05	0.10	...	...	...	...	0.09	0.12	12
Heliotropium convovulaceum	...	...	...	...	...	...	0.40	0.10	0.05	0.10	0.09	0.04	4
Heterotheca latifolia	0.92	0.50	0.20	0.20	0.90	1.00	1.40	1.00	1.00	0.50	0.84	0.64	36
Melampodium leucanthum	...	...	...	...	0.05	0.10	...	...	...	...	0.01	0.02	2
Phyllanthus abnormis	0.15	0.30	0.32	0.50	0.25	0.40	0.00	0.10	0.35	0.30	0.23	0.32	22
Pectis papposa	0.95	1.30	1.30	2.40	1.00	0.80	...	...	0.15	0.20	0.68	0.94	38
Houstonia humifusa	0.80	2.20	0.25	0.40	0.55	1.20	0.40	0.80	0.70	0.80	0.70	1.08	32
Artemisia filifolia	1.20	0.30	6.80	0.50	0.20	0.20	8.20	0.20	...	...	3.28	0.24	14
Quercus havardii	5.50	1.10	7.40	1.00	7.50	0.70	19.10	1.40	14.00	2.70	10.30	1.08	32
Senecio spartoides	1.80	0.20	...	...	...	...	0.50	0.10	0.20	0.10	0.50	0.08	8
Lesquerella sp.	0.07	0.20	...	...	0.20	0.40	...	...	...	...	0.05	0.12	6
Dalea sp.	...	...	...	...	...	...	0.05	0.00	0.20	0.30	0.05	0.06	6
Hymenopappus sp.	0.17	0.30	...	...	...	...	...	...	...	...	0.03	0.06	6
Caesalpinia sp.	...	...	...	...	...	...	0.10	0.10	...	...	0.02	0.02	2
Croton dioicus	1.00	0.10	...	...	...	...	...	...	...	...	0.20	0.02	2
Monarda sp.	...	...	0.10	0.10	...	...	...	...	...	...	0.02	0.02	2
Gaura sp.	...	...	...	...	...	...	...	...	0.20	0.20	0.04	0.04	2
Litter	21.00	0.00	31.70	0.00	40.00	0.00	33.50	0.20	19.90	0.00	29.32	...	100

Table 6.20. Averaged canopy cover (C) and density (D) of plants found inside the BLM Highway exclosure.

Species	Transect 101		102		103		104		105		Average		Frequency Percent
	C	D	C	D	C	D	C	D	C	D	Cover	Density	
Aristida purpurea	0.40	0.10	0.80	0.30	1.90	0.60	...	...	1.00	0.20	0.82	0.24	12
Bouteloua eriopoda	...	...	1.50	0.30	13.50	2.80	0.20	0.20	12.00	2.30	5.44	1.12	24
Bouteloua hirsuta	2.10	0.60	0.60	0.10	...	...	2.90	0.20	...	...	1.12	0.18	12
Brachiaria ciliatissima	1.20	0.80	3.50	2.70	1.80	1.00	2.90	1.70	7.00	3.00	3.27	1.84	52
Cenchurus incertus	...	...	1.00	0.40	...	...	0.50	0.10	0.50	0.10	0.40	0.12	10
Eragrostis oxylepis	...	...	...	...	...	...	...	...	1.10	0.10	0.22	0.02	4
Leptoloma cognatum	5.20	5.10	1.90	2.10	1.18	1.20	2.00	1.50	5.60	3.60	3.17	2.72	44
Munroa squarrosa	...	...	0.05	0.10	0.40	0.20	0.20	0.20	...	...	0.13	0.10	10
Paspalum setaceum	1.90	0.50	0.30	0.30	...	...	...	...	0.10	0.10	0.46	0.27	8
Sporobolus cryptandrus	...	...	7.10	1.60	...	...	...	...	...	...	1.42	0.32	12
Aristida divaricata	2.10	0.50	1.20	0.30	0.80	0.30	0.01	0.20	...	...	0.82	0.42	14
Aristida sp.	0.20	0.20	0.20	0.30	...	...	0.10	0.10	0.60	0.10	0.22	0.14	8
Cyperus sp.	...	...	...	...	...	...	0.10	0.10	...	...	0.02	0.02	2
Muhlenbergia porteri	1.00	0.10	...	...	...	...	...	...	...	...	0.20	0.02	2
Eragrostis sessilispica	0.80	0.20	...	...	1.50	0.10	1.20	0.10	...	...	0.70	0.08	8
Sporobolus sp.	1.25	0.40	...	...	0.40	0.20	7.60	0.90	0.50	0.30	1.94	0.36	24
Panicum obtusum	...	...	...	...	0.50	0.10	...	...	...	...	0.10	0.02	2
Bothriochloa sp.	...	...	1.50	0.10	...	...	...	...	...	...	0.30	0.02	2
Phyllanthus abnornum	...	...	...	...	0.20	0.10	0.20	0.20	...	...	0.08	0.06	6
Eriogonum annuum	...	...	...	...	0.50	0.30	...	...	...	...	0.10	0.06	8
Caesalpina sp.	...	...	1.00	0.10	...	...	...	...	...	...	0.20	0.02	2
Artemisia filifolia	...	...	0.01	0.00	0.50	0.10	0.50	0.00	6.50	0.10	1.50	0.04	4
Quercus havardii	8.80	1.00	10.20	1.40	5.30	1.00	7.50	2.00	4.40	0.70	7.24	1.22	54
Yucca sp.	5.00	0.10	3.00	0.10	...	...	7.50	0.20	5.50	0.00	4.20	0.08	100
Litter	52.65	0100	45.50	0.00	59.00	0.00	55.50	0.00	59.00	0.00	56.33	0.00	100

Table 6.21. Averaged canopy cover (C) and density (D) of plants found on the outside of the BLM Highway exclosure.

Species	Transect 96 C	Transect 96 D	Transect 97 C	Transect 97 D	Transect 98 C	Transect 98 D	Transect 99 C	Transect 99 D	Transect 100 C	Transect 100 D	Average Cover	Average Density	Frequency Percent
Aristida purpurea	1.50	0.10	3.20	0.60	1.50	0.40	2.50	0.50	1.90	0.30	2.12	0.38	20
Bouteloua eriopoda	...	...	3.30	2.40	...	...	0.90	0.80	0.40	0.00	0.92	0.64	18
Bouteloua hirsuta	...	...	...	...	0.20	0.20	0.20	0.20	1.00	0.40	0.28	0.16	12
Brachiaria ciliatissima	13.10	6.80	3.90	1.80	4.20	1.90	...	...	1.40	0.60	4.53	2.22	54
Cenchrus incertus	0.15	0.20	1.30	0.40	...	...	1.70	0.40	1.60	0.60	0.95	0.32	28
Eragrostis oxylepis	...	...	...	...	...	...	...	...	0.60	0.30	0.12	0.06	2
Leptoloma cognatum	2.00	2.30	2.50	2.20	14.60	3.40	5.90	4.30	1.80	1.70	5.37	2.78	50
Munroa squarrosa	0.55	0.30	0.30	0.40	0.30	0.50	0.60	0.60	0.20	0.10	0.49	0.38	26
Paspalum setaceum	...	...	...	...	...	...	...	...	0.80	0.50	0.16	0.10	4
Sporobolus cryptandrus	...	...	2.60	1.80	...	...	...	...	...	...	0.52	0.36	8
Aristida divaricata	0.80	0.20	3.00	0.40	0.90	0.40	1.90	1.00	1.20	0.20	1.56	0.44	20
Aristida wrightii	...	...	...	...	...	...	0.10	0.10	1.40	0.40	0.30	0.10	6
Aristida sp.	...	...	0.90	0.60	0.30	0.10	1.00	0.50	0.20	0.20	0.49	0.28	14
Cyperus sp.	...	...	0.20	0.20	...	...	...	...	...	...	0.04	0.04	2
Eragrostis sessilispica	0.80	0.10	1.50	0.10	0.10	0.10	...	...	0.50	0.20	0.58	0.10	10
Sporobolus sp.	3.80	1.60	...	...	2.30	0.50	1.00	0.50	3.40	0.80	2.10	0.68	40
Sporobolus flexuosus	...	...	...	...	...	...	...	...	0.40	0.20	0.08	0.04	2
Senecio spartoides	...	...	...	...	0.10	0.10	...	...	...	...	0.02	0.02	2
Dalea sp.	...	...	...	...	0.30	0.10	...	...	...	...	0.01	0.02	2
Caesalpinia sp.	...	...	...	...	0.20	0.20	...	...	...	...	0.04	0.04	2
Artemisia filifolia	7.50	0.30	0.50	0.00	...	...	0.90	0.10	4.10	0.20	2.58	0.12	10
Quercus havardii	13.00	2.10	16.90	2.20	15.70	1.80	11.20	2.00	12.10	1.80	13.78	1.98	69
Yucca sp.	...	...	0.20	0.00	10.50	0.10	...	...	3.10	0.20	2.26	0.06	6
Litter	41.60	0.00	47.50	0.00	42.10	0.00	45.00	0.00	46.50	0.00	44.54	0.00	100

Table 6.22. Averaged canopy cover (C) and density (D) of plants found inside the WIPP Site section 15 exclosure-to-be.

Species	Transect 106 C	106 D	107 C	107 D	108 C	108 D	109 C	109 D	110 C	110 D	Average Cover	Average Density	Frequency Percent
Aristida purpurea	...	...	...	...	...	...	...	...	0.50	0.10	0.10	0.02	2
Bouteloua eriopoda	0.60	0.40	...	...	...	...	1.00	0.30	0.90	0.60	0.50	0.26	10
Cenchrus incertus	0.40	0.30	0.35	0.50	0.40	0.50	0.10	0.10	0.45	0.40	0.34	0.36	22
Leptoloma cognatum	0.30	0.40	0.30	0.60	1.20	2.00	...	...	2.10	2.40	0.78	1.08	16
Munroa squarrosa	2.65	3.40	3.10	2.90	0.65	0.10	4.80	3.70	5.70	4.60	3.38	2.94	72
Paspalum setaceum	...	...	0.50	0.30	0.80	0.20	0.80	0.20	...	...	0.42	0.14	8
Sporobolus cryptandrus	...	...	...	...	1.60	0.60	...	...	...	...	0.32	0.12	8
Aristida sp.	0.40	0.10	2.70	1.20	...	...	2.70	0.50	0.70	0.30	1.30	0.42	20
Cyperus sp.	0.10	0.10	...	...	...	...	...	...	...	...	0.02	0.02	2
Eragrostis sessilispica	1.00	0.10	...	...	...	...	...	...	...	...	0.20	0.02	2
Sporobolus sp.	4.65	1.70	1.60	0.80	0.60	0.20	1.60	0.80	0.10	0.10	1.71	0.72	42
Eriogonum annuum	...	...	...	...	...	...	0.01	0.10	...	...	0.01	0.02	2
Phyllanthus sp.	...	...	...	...	0.01	0.10	...	...	...	...	0.01	0.02	2
Pectis sp.	0.78	1.70	0.85	2.60	0.30	2.00	1.55	2.70	0.10	0.20	0.71	1.84	32
Unknown	...	...	...	...	...	...	0.20	0.10	...	...	0.04	0.02	2
Caesalpinia sp.	0.10	0.10	...	...	...	...	...	...	...	...	0.02	0.02	2
Portulaca mundula	0.05	0.50	...	...	...	...	...	...	...	...	0.01	0.01	6
Mollugo sp.	...	...	...	...	...	...	0.10	0.05	...	...	0.02	0.01	2
Artemisia filifolia	5.10	0.20	0.20	0.20	0.60	0.30	4.60	0.20	0.30	0.00	2.16	0.18	18
Quercus havardii	11.90	4.00	6.00	3.20	17.30	1.60	9.30	3.30	14.00	2.70	11.70	2.96	72

Table 6.23. Averaged canopy cover (C) and density (D) of plants recorded on the outside of Section 15 exclosure-to-be on the WIPP site.

Species	Transect 121 C	Transect 121 D	Transect 122 C	Transect 122 D	Transect 123 C	Transect 123 D	Transect 124 C	Transect 124 D	Transect 125 C	Transect 125 D	Average Cover	Average Density	Frequency Percent
Aristida purpurea	...	...	0.80	0.20	0.40	0.30	3.10	0.80	0.10	0.10	8.80	0.28	18
Bouteloua eriopoda	0.20	0.20	...	...	...	...	0.40	0.10	0.60	0.20	0.24	0.99	6
Cenchrus incertus	...	...	1.35	1.00	0.20	0.30	0.50	0.30	0.30	0.30	0.47	0.58	20
Leptoloma cognatum	0.40	0.50	0.10	0.10	0.30	0.20	...	...	0.60	0.40	0.36	0.24	14
Munroa squarrosa	0.10	0.20	2.15	2.00	0.40	0.80	2.15	1.90	12.40	2.70	3.44	1.52	52
Paspalum setaceum	...	...	0.30	0.30	0.20	0.30	...	...	0.50	0.10	0.20	0.14	10
Sporobolus cryptandrus	...	...	2.60	0.60	1.30	0.70	1.00	0.40	0.80	0.40	1.14	0.42	28
Aristida divaricata	2.90	0.70	...	...	...	...	...	...	...	...	0.58	0.14	8
Aristida sp.	3.50	2.10	0.80	0.40	...	...	...	...	0.30	0.50	0.92	0.60	20
Cyperus sp.	0.40	0.10	...	...	...	...	0.20	0.10	...	...	0.12	0.04	4
Eragrostis sessilispica	0.30	0.10	...	...	...	...	...	...	0.01	0.01	0.06	0.02	4
Sporobolus sp.	0.35	0.40	...	...	...	...	...	...	...	...	0.07	0.08	6
Sporobolus flexuosus	1.00	0.20	1.40	0.30	...	...	0.50	0.30	0.70	0.50	0.52	0.26	14
Commelina erecta	0.10	0.10	...	...	...	...	...	...	...	...	0.02	0.02	2
Croton sp.	0.40	0.10	...	...	...	...	...	...	0.05	0.10	0.09	0.04	4
Eriogonum annuum	0.05	0.10	...	...	...	...	0.30	0.20	...	...	0.07	0.06	6
Heliotropium convolvulaceum	0.10	0.20	0.20	0.30	0.40	0.60	...	...	...	...	0.14	0.22	12
Melampodium leucanthum	0.60	0.20	0.10	0.10	0.90	0.30	...	...	...	...	0.32	0.12	8
Mirabilis sp.	...	...	0.10	0.10	...	...	...	...	...	...	0.02	0.02	2
Euphorbia fendleri	0.01	0.10	...	...	...	...	...	...	...	...	0.01	0.02	2
Dalea sp.	...	...	...	...	0.01	0.10	0.50	0.20	...	...	0.10	0.06	4
Portulaca mundula	0.02	0.10	...	...	...	...	0.10	0.20	...	...	0.02	0.04	4
Artemisia filifolia	9.00	0.10	12.00	0.10	9.10	0.20	...	...	0.30	0.00	6.08	0.08	10
Prosopis glandulosa	...	...	...	...	7.40	0.60	4.00	0.00	...	...	2.28	0.12	4
Quercus havardii	3.50	0.80	5.00	1.60	4.70	0.60	11.40	2.00	12.40	2.70	7.40	2.57	50
Litter	30.00	0.00	38.50	0.00	43.40	0.00	30.00	0.00	29.30	0.00	34.24	0.00	

Table 6.24. Averaged canopy cover (C) and density (D) of plants recorded outside the section 20 exclosure-to-be on the WIPP site.

Species	Transect 136 C	136 D	137 C	137 D	138 C	138 D	139 C	139 D	140 C	140 D	Average Cover	Average Density	Frequency Percent
Aristida purpurea	...	...	1.00	0.20	...	...	1.00	0.30	1.20	0.60	0.64	0.22	12
Cenchrus incertus	...	...	...	...	1.00	0.50	0.80	0.10	0.20	0.10	0.32	0.14	8
Leptoloma cognatum	...	...	...	...	0.30	0.00	1.40	1.30	0.40	0.10	0.42	0.28	8
Munroa squarrosa	...	...	0.80	0.20	0.60	0.50	0.20	0.20	1.40	0.50	0.60	0.28	22
Paspalum setaceum	...	...	...	...	1.40	0.60	0.60	0.10	...	...	0.40	0.14	6
Aristida divaricata	...	...	...	...	...	...	2.50	0.40	...	...	0.50	0.08	8
Aristida sp.	...	...	1.20	0.40	...	...	0.50	0.10	...	...	0.28	0.10	4
Sporobolus sp.	29.80	2.90	15.80	3.00	9.20	2.40	8.12	2.50	13.20	2.70	15.22	2.70	94
Sporobolus flexuosus	2.50	0.10	...	...	...	...	...	...	...	...	0.50	0.02	2
Croton sp.	...	...	...	...	0.10	0.10	...	...	...	...	0.02	0.02	2
Eriogonum annuum	0.33	0.50	0.65	0.40	0.95	1.30	1.10	0.90	1.10	0.90	0.83	0.80	44
Euphorbia missourica	...	...	0.50	0.10	2.80	0.00	...	...	...	...	0.66	0.02	6
Heleanthus sp.	1.50	0.30	...	...	1.90	0.40	0.50	0.10	0.80	0.20	0.94	0.20	22
Mentzelia sp.	...	...	...	...	...	...	...	...	0.05	0.10	0.01	0.02	2
Mirabilius sp.	...	...	...	...	...	...	...	...	0.10	0.10	0.02	0.02	2
Phyllanthus abnormum	...	...	0.40	0.40	0.35	0.30	0.20	0.10	...	...	0.19	0.16	12
Solanum sp.	...	...	...	...	...	...	...	...	0.10	0.10	0.02	0.02	2
Pectis sp.	0.10	0.10	0.10	0.10	0.10	0.10	0.20	0.10	0.70	0.70	0.24	0.22	6
Houstonia sp.	0.30	0.40	...	...	0.05	0.30	0.05	0.02	...	...	0.08	0.14	6
Hymenopappus sp.	...	...	...	...	0.10	0.10	...	...	...	...	0.02	0.02	2
Artemisia filifolia	5.10	0.20	10.00	0.10	5.00	0.10	1.10	0.10	3.00	0.00	4.84	0.10	10
Quercus havardii	1.10	0.40	0.40	0.30	...	...	0.80	0.30	0.50	0.10	0.56	0.22	20
Yucca sp.	10.50	0.30	2.00	0.10	1.00	0.00	...	...	...	...	2.70	0.08	6
Litter	55.00	0.00	60.00	0.00	48.00	0.00	43.90	0.00	70.00	0.00	55.50	0.00	...

Table 6.25. Averaged canopy cover (C) and density (D) of plants recorded outside the section 20 exclosure-to-be on the WIPP site.

Species	Transect 141 C	Transect 141 D	Transect 142 C	Transect 142 D	Transect 143 C	Transect 143 D	Transect 144 C	Transect 144 D	Transect 145 C	Transect 145 D	Average Cover	Average Density	Frequency Percent
Aristida purpurea	4.00	0.90	...	...	...	...	...	...	...	...	0.80	0.18	6
Bouteloua eriopoda	1.20	0.40	...	...	0.40	0.00	...	...	...	...	0.32	0.08	4
Bouteloua hirsuta	...	...	0.10	0.20	0.40	0.10	...	...	...	...	0.10	0.06	4
Cenchrus incertus	0.70	0.40	0.40	0.30	0.80	0.20	1.40	0.40	1.20	0.40	0.90	0.53	26
Eragrostis oxylepis	0.60	0.30	...	...	...	...	...	...	...	...	0.12	0.06	4
Leptoloma cognatum	1.50	0.50	0.40	0.40	1.90	0.60	1.00	0.50	1.70	2.10	1.30	0.82	22
Munroa squarrosa	0.20	0.10	0.60	0.40	0.45	0.40	3.30	1.20	0.80	0.50	1.07	0.52	36
Paspalum setaceum	...	...	...	...	...	...	...	...	1.50	0.30	0.30	0.60	4
Sporobolus cryptandrus	...	...	...	...	...	...	...	...	0.30	0.10	0.06	0.20	2
Aristida divaricata	0.50	0.10	...	...	...	...	...	...	...	...	0.10	0.20	2
Aristida sp.	0.20	0.10	1.00	0.20	0.10	0.10	...	...	...	...	0.26	0.08	8
Cypreus sp	0.30	0.20	...	...	...	...	...	...	...	...	0.06	0.04	4
Sporobolus sp.	10.10	2.70	11.20	3.10	17.50	3.90	10.15	1.40	15.70	2.40	12.93	2.70	90
Commelina erecta	...	...	...	...	0.40	0.00	...	...	...	...	0.80	0.00	
Eriogonum annuum	0.45	0.60	0.42	0.60	0.30	0.30	1.95	1.90	0.10	0.10	0.64	0.70	34
Euphorbia missurica	0.30	0.00	...	...	2.00	0.00	0.80	0.10	...	...	0.62	0.02	2
Heliotropium convolvulaceum	2.20	0.00	...	...	...	...	...	...	0.10	0.10	0.46	0.02	2
Heleanthus sp.	1.70	0.20	0.40	0.10	...	...	0.10	0.10	...	...	0.44	0.08	6
Mentzelia sp.	0.20	0.10	...	...	...	...	...	...	...	...	0.04	0.02	2
Phyllanthus sp.	0.05	0.10	0.03	0.10	0.10	0.10	0.40	0.10	0.10	0.10	0.14	0.10	10
Pectis sp.	0.20	0.30	0.30	0.30	0.05	0.10	0.10	0.10	...	...	0.13	0.16	10
Houstonia sp	...	...	1.35	2.20	0.60	0.90	1.60	1.90	0.15	0.40	0.68	1.08	26
Quercus havardii	2.80	0.70	0.50	0.10	1.50	0.60	0.60	0.20	3.40	0.30	1.76	0.36	22
Heterotheca latifolia	...	...	...	...	...	...	0.70	0.20	0.20	0.00	0.18	0.04	6
Solanum sp.	...	...	0.20	0.20	...	...	...	...	...	...	0.04	0.04	2
Litter	57.30	0.00	37.40	0.00	45.00	0.00	47.60	0.00	36.50	0.00	43.56	0.00	

Table 6.26. Averaged canopy cover (C) and density (D) of plants found on the shortgrass prairie mesa WIPP site southeast of Carlsbad, New Mexico.

Species	Transect 47 C	47 D	48 C	48 D	49 C	49 D	50 C	50 D	51 C	51 D
Grasses:										
Bouteloua eriopoda	7.80	12.00	11.30	7.30	5.50	4.60	6.00	6.70	0.30	0.30
Leptoloma cognatum	0.05	0.10	...	...	1.60	6.00	...	...	0.60	1.10
Erioneuron pulchellum	6.70	18.60	3.10	9.90	0.80	1.50	3.95	5.80	0.01	0.10
Aristida sp.	0.10	0.10	0.40	0.70	1.20	0.60	0.20	0.40	0.60	0.70
Muhlenbergia torreyi	0.40	0.60	4.20	2.20	0.95	1.40	3.85	2.30	...	...
Muhlenbergia porteri	5.50	2.50	...	...	...	...	...	...	10.20	1.90
Tridens sp.	...	...	2.67	1.60	...	...	...	...	...	...
Scleropogon brevifolius	...	...	...	...	22.40	43.50	...	...	...	...
Eragrostis curtipedicellata	...	...	...	...	...	...	...	...	1.10	3.10
Setaria macrostachya	...	...	...	...	...	...	...	...	0.10	0.10
Sporobolus sp.	...	...	...	...	...	...	...	...	0.70	0.70
Forbs:										
Solanum sp.	0.07	0.30	0.01	0.20	...	...	...	...	0.70	1.10
Lesquerella sp.	0.47	4.60	0.40	2.90	0.58	2.70	0.75	4.20	0.01	0.10
Unknown	0.01	0.10	...	...	0.01	0.10	0.01	0.10	0.01	0.10
Dyssodia sp.	0.20	0.10	...	...	...	...	...	...	...	...
Cryptantha sp.	0.08	0.40	...	...	0.01	0.10	0.05	0.10	...	...
Mallow	0.02	0.10	...	...	0.25	0.30	2.05	2.50	0.01	0.10
Mirabilis sp.	...	...	0.03	0.10	...	...	...	...	...	...
Euphorbia sp.	...	...	0.02	0.10	...	...	...	...	...	...
Unknown comp.	...	...	0.15	1.60	0.20	0.90	...	...	...	...
Verbena sp.	...	...	...	...	0.05	0.20	...	...	...	...
Croton sp.	...	...	...	...	...	...	0.10	0.10	0.93	1.10
Gutierrezia dracunculoides	...	...	...	...	...	...	0.70	0.40	...	...
Haplopappus sp.	...	...	...	...	...	...	0.20	0.00	...	...
Eriogonum annuum	...	...	...	...	...	...	...	...	0.10	0.80
Sphaeralcea coccinea	...	...	...	...	...	...	...	...	0.30	0.10
Artemisia ludoviciana	...	...	...	...	...	...	...	...	0.01	0.30
Shrubs:										
Prosopis glandulosa	7.50	1.00	3.20	0.20	...	...	8.30	0.20	3.20	0.90
Gutierrezia sarothrae	0.80	1.60	0.60	0.80	0.45	0.80	2.00	0.70	2.30	1.20

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CHAPTER 7

MICROBIAL BIOGEOCHEMISTRY

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Introduction

This chapter is a preliminary description of the microbial flora and its potential biogeochemical impact for the WIPP. The results must be considered preliminary because they represent only a fraction of one year and do not consider seasonal or annual changes which could occur. This study defines the key physical and microbial state variables necessary to model the WIPP site for biological monitoring. The objective of the model is to monitor the effects of salt dispersal and other physical activities on mass transport. It may also be used as the basis for prediction of radionuclide transport. The choice of physicochemical state variables, biological state variables, and response equations to be included in this model is based on the model objectives, past biome models, and the unique characteristics of the WIPP site and vicinity.

The microbial biogeochemistry of the WIPP site can be divided into four major categories: surface waters, surface soils, subsurface salt beds, and subsurface aquifers. The objective of microbial biogeochemical investigation for the current period, January 1978-September 1978, was to identify and quantitate some of the key microbial agents and processes occurring in surface soils. During the course of investigation, this objective was expanded to include surface waters (cattle watering tanks, Laguna Grande de la Sal, and the Pecos River).

Unlike the biogeochemistry of C, N, S, P, Fe, Hg and a few other elements, the microbial biogeochemistry of radionuclides present in nuclear wastes is unknown. Thus, while it is possible to pinpoint the sites for the key biogeochemical transformations of C, N, S, P, Fe, and Hg (Table 7.1), it is only possible to speculate concerning the key sites for biogeochemical transformations of actinides and other radionuclides present in nuclear waste. However, analogies between the actinides and other elements suggest that there are critical sites where hazardous transformations or bioconcentration could occcur.

Microbial transport of radionuclides has been demonstrated by the movement of plutonium (Pu-238) through fungal mycelia to fungal spores (Aspergillus niger, a mold).[1,2,3] Transport occurred at pH 2.5 and pH 5.5, at Pu concentrations of 2.7×10^{-11} to 10.8×10^{-11} moles per liter, and using three chemical forms of Pu-238 (nitrate, citrate, and dioxide).[1,2,3] Although transport to the spores occurred, there was no bioconcentration. In additional studies, U-235, U-238, Th-232, and Po-210 were also transported to the fungal spores. It has also been shown that Cs-137 is accumulated in mushrooms.[4] Thus one existing mechanism of mobilization is from decomposing wastes to the atmosphere via spore-forming fungi. These fungi have been found at the Nevada Test Site.[5]

This is the present extent of knowledge concerning microbial mobilization of radionuclides. Areas in need of further investigation include the production and decomposition of chelating agents, metabolic changes in radionuclide oxidation state, microbial alkylation, and microbial adsorption. Each of these is discussed below.

Bioconcentration-Microbial Degradation of Radionuclide Chelates

The oxidation state of actinides varies from 2 to 7 and the most stable oxidation state for each actinide varies from +3 to +6. The stable states for the uranium, plutonium, and americium ions are +6, +4, and +3, respectively.[6] In aqueous solutions, plutonium can exist as PuO_2 (PuIV

precipitate), PuO_2^{2+} (PuVI), or Pu^{4+} (PuIV). The latter two forms can complex with OH^-, CO_3^{2-}m, and other anions or with organics.[7] Since Pu^{4+} is a cation, it binds to chelating agents which can increase its solubility.[6] Humic compounds, which are produced microbially during lignin degradation, do not seem to alter appreciably the solubility of plutonium or americium in soil.[8]

Chelating agents have been shown to cause low-level migration of radionuclides from the Oak Ridge National Laboratory burial grounds.[9] If the organic portion of the chelate is degraded microbially, the cation is released. If no other chelates are available, the cation then forms an insoluble precipitate.[10,11,3] This is one of the most common mechanisms responsible for iron fouling of water pipes by iron-depositing bacteria[10] and the presence of iron depositions in the Carlsbad Caverns. Citrate, tartarate, ethylenediamine tetraacetic acid (EDTA), and nitrilotriacetate (NTA) are commonly used in cleaning solutions and would be expected in radioactive wastes.

Many microorganisms produce chelates. Some of these are nonspecific and are produced as metabolic by-products. Others, like the hydroxamates and enterochelins, are potent chelates produced primarily when microbial cells are grown on iron deficient media. Hydroxamate chelating agents are commonly produced by bacteria and fungi. These agents would probably be produced during decomposition of cellulosic and other TRU wastes,[12,13] and would also be present in soil and water. The hydroxamate chelates are a class of compounds resulting in a bidentate chelate with ferric ion. By repeating the hydroxamate unit several times in a single molecule, stronger chelates such as ferrichrome (hexadentate), can be produced microbially.

All of these chelates are biodegradable, but no degradation studies of the hydroxamate chelates have been performed. EDTA degrades negligibly, NTA slowly, and citrate and tartarate rapidly. Chelate degradation studies are often performed using sodium as the cation. When other cations are used, the rate of degradation often decreases or the chelating agent becomes nonbiodegradable.[14] As a result, the rate at which

microorganisms degrade radionuclide chelates must be determined for each radioactive cation under the conditions anticipated for the WIPP. This information is not yet available.

There are two possible outcomes if microbial degradation of radionuclide chelates occurs: (1) soluble radionuclides will be degraded and the radioactive material precipitated; (2) radionuclide chelates may enter surface or subsurface aquifers and be bioconcentrated by chelate-degrading microorganisms attached to mineral, plant, or animal surfaces.

Bioconcentration-Changes in Radionuclide Oxidation State Due to Microbial Metabolism

As in the case of chelates, changes in the radionuclide oxidation state can cause either solubilization or precipitation. The precipitates may form a sediment or be filtered out by the movement of water through porous rock, resulting in a criticality event.

Cm(III) and Th(IV) have relatively stable oxidation states. However, Np and Pu have variable oxidation states.[7] The oxidation states for Np and Pu vary from +3 to +7.[6] The most stable oxidation state is +5 for neptunium and +4 for plutonium. The most common forms of plutonium in soil and other environments are (PuIV), Pu^{+4} ion, and (PuVI) as PuO_2^{+2}.[7] Pu^{+4} is readily complexed by chelating agents which may be present in waste, while plutonium dioxide is highly insoluble. Thus, microbial oxidation of (PuIV) to (PuVI) may result in bioconcentration by precipitation. However, there are no studies regarding the ability of microorganisms to alter directly the oxidation states of actinides. Microbial solubilization of uranium dioxide in leaching operations occurs indirectly by microbial production of sulfate from sulfide, which permits the subsequent chemical reaction of sulfate and UO_2 (insoluble) to form UO_2SO_4 (soluble).[15] Due to the numerous elements or compounds which are used either as electron donors or acceptors for microbial growth (Ag, As, Bi, Cd, Cu, Fe, Mn, Ni, S, Se, Te, U, V, Zn),[11] it is likely that bioconcentration due to changes in the radionuclide oxidation state (or

to microbial redox reactions involving radionuclide-containing compounds) will occur.

Bioconcentration-Adsorption to Microbial Surfaces

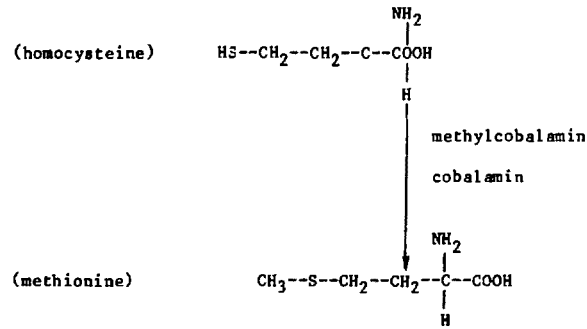
One potential mechanism of radionuclide bioconcentration is adsorption. In some cases, the cation of interest may simply displace another which is more weakly chelated to the surface or internal molecules of the microorganism. In the case of microbial holdfasts, capsules, and sheaths, iron and manganese have been found to specifically accumulate at high concentrations.[16,11,17-21,10,22,23,24] In the case of Pedomicrobium sp., metal deposition is restricted only to the portions of the cells covered by attachment polysaccharides.[25,26] Fe^{+3} and/or Mn^{+3} is deposited in the extracellular polysaccharides of all of these bacteria if Fe^{+2} or Mn^{+2} (the reduced ionic or metallic form of each) is present in solution or as a metal near (1-2 cm) the site of microbial colonization. The chemical mechanisms of adsorption are unknown. If adsorption should also be a mechanism of radionuclide bioconcentration, it may continue past the concentration lethal to the bacteria involved, since only the extra cellular polysaccharide may be involved in bioconcentration. Of the radionuclides, technetium is most similar to iron and manganese in chemical properties; but it is undetermined whether technetium could be bioconcentrated as are iron and manganese.

Mobilization and Subsequent Bioconcentration - Volatilization of Radionuclides via Alkylation Reactions

The alkylation of plutonium or other radionuclides, such as methyl iodide (I-25), would result in the release of an organic form of the radionuclide in soil and water which, due to its decreased polarity, would be bioconcentrated in plant and animal tissues. This is a potential problem because microorganisms are known to alkylate numerous other elements.

A well-known microbial alkylation reaction for metals is the methylation of mercury,[27] which occurs in clay, loam and sandy soils.[28] Both fungi and bacteria have been shown to be responsible for this alkylation reaction.[11] Microbial alkylation generally occurs anaerobically and aerobically.[27,29] Separate aerobic and anaerobic mechanisms have been proposed but both involve methylcobalamin.

Methylation of mercury is restricted to microorganisms due to the unique microbial pathway for the biosynthesis of methionine. Using this biosynthetic pathway the methyl group of methylcobalamin is transferred to homocysteine forming methionine.[30]



Neither this reaction nor the methylation of metals occurs in higher organisms. Metals are alkylated nonenzymatically by methylcobalamin.[31] Thus, the formation of cyanocobalamin is an enzymatic, biological process while the subsequent formation of alkylated elements is a chemical process. In the case of mercury, it is the mercury-resistant organisms that are capable of alkylation. In addition, the presence of mercury-metabolizing bacteria caused a 200-fold bioconcentration of mercury in oysters.[32] Methylation of mercury is a common phenomenon which occurs in clay, loam, and sandy soils.[28]

In addition to mercury, the metals Sn, Pd, Pt, Au, and Tl, as well as the metalloids As, Se, Te, and S, are methylated.[29,33] Upon being methylated the metals become volatile and less polar (making them more soluble in biological tissues). Biological methylation has not yet been found to occur in the case of Cd, Pb, and Zn.

The optimum conditions for methylation seem to be aerobic, with cysteine, vitamin B_{12}, and mercuric chloride in the medium. The actinides should be incubated under these conditions to determine whether alkylation is possible. In the case of tellurium, methylation occurs only when selenium is in 10-fold excess. This indicates that transalkylation may occur as an indirect result of microbial alkylation.[34] Thus, the possibility of the transalkylation from methylated Sn, Pd, Pt, Au, Tl, S, As, Se, and Te to actinides should also be considered.

Field Studies

Direct Counts of Soil

Studies of the soil microflora are being conducted for shinnery oak and barren soil. Five replicate stations (selected randomly) are included for each. Microbial populations in soil were quantified directly by autofluorescence or by induced fluorescence for cells treated with acridine orange.[35]

Colonization of Glass Slides, EM Grids, Cellulose Film, Leaves and Roots

Since it is difficult to directly enumerate all microorganisms in soil due to the large amount of detritus present, sterilized glass slides are being incubated vertically in soil. The level of the soil surface is marked on the slide at the time of collection. They are returned to the laboratory and observed for microbial growth. Highly purified strips of cellulose are also incubated in soil and observed for microbial growth. Leaves (collected as they fall using nylon mesh) and roots are incubated in 2 mm mesh nylon bags in the fall and observed directly for colonization by microorganisms.

In order to ensure that no microorganisms are overlooked using the above methods, electron microscope (EM) grids are fixed to glass slides, pressed on the soil surface, and weighted to prevent them from being blown away. The EM grids are sterilized using ethylene oxide before incubation and checked for contamination by dead bacterial cells prior to incubation. The grids are shadowed using a carbon-platinum coating and then observed using a transmission electron microscope.

Halophilic Microorganisms

The procedures listed in Standard Methods are used to plate the bacteria. However, the soil is first homogenized using glass beads at 50,000 rpm[36] to break up clumps and HM2 medium is used for cultivation.

Medium HM2

g/l	
10.0	yeast extract
5.0	protease peptone
5.0	casamino acids
2.0	KCl
20.0	$MgSO_4 \cdot 7H_2O$
250.0	NaCl
15.0	agar

Thermophilic Microorganisms

Thermophilic microorganisms are enumerated using liquid dilution tubes of nitrate broth. Dilution tubes were used instead of agar plates due to the instability of agar plates at high temperature. Nitrate broth was used since some of the thermophiles found in the region prefer nitrate to oxygen as an electron acceptor.[37] The maximum daily soil crust temperature ranges from 60-70°C during midsummer. The minimum temperature for *Thermothrix* sp., an obligate thermophile from New Mexico hot springs,

is 55°C. As a result an incubation temperature of 60°C was chosen to enumerate both obligate and facultative thermophiles.

Chlorophylls a and b and Phycocyanin

Chlorophylls a and b are determined by spectrofluorimetry[38] using an excitation of 428 and emission of 666 for chlorophyll a and an excitation of 453 and emission of 646 for chlorphyll b in ethyl ether. An excitation of 570 and emission of 788 was used for bacteriochlorophyll a.

Phycocyanin (the primary accessory pigment of the Cyanobacteria) is determined by fluorometry. Since there are no commercially available standards, these were prepared by isolation, crystallization, and lyophilization of phycocyanin from natural material (unpublished results). Phycocyanin has not previously been used as a biological state variable in ecosystem studies.

Primary Amines

Primary amines (primarily amino acids, peptides, and protein) are extracted and determined by the fluorescamine assay.[39,40] Since most of the primary amines present in vivo are proteins, it is assumed that primarily protein is measured, and bovine serum albumen was used as a standard. Controls using cold 10% trichloroacetic acid (TCA) to precipitate the protein before assaying show that the fluorescence is in fact due to protein. Phytoplankton productivity was determined as described in Standard Methods for the Examination of Water and Wastewater.[41]

Results

Los Medaños Soil Crust

The soil covering most of the site consists of shifting sands occasionally stabilized by a blue-green crust. The crust consisted of nonmotile bundles of cyanobacterial filaments enclosed in a common thick, multilaminate sheath. These fall in the genus Schizothrix since no heterocysts were observed. Similar, but heterocystic, blue-greens have

previously been reported in desert crusts. These belong to the genus Scytonema.[42] The blue-green crusts were found in areas with shinnery oak, sage, and mesquite as the major plant types. There was an inoculum of cyanobacterial cells present throughout these areas during the summer months. The background level of chlorophyll was 50 ± 47 (95% confidence interval, s = 61) nanograms per cm^2. The crust becomes visible macroscopically only during moist periods as sporadic dark-green patches on the soil surface.

In the southeast corner of the WIPP site there is an extensive creosotebush (Larrea tridentata) area where the caliche is near the surface. In these areas the blue-green crusts occur but are relatively insignificant in comparison to green lichens which dominate the soil crust. The concentration of chlorophyll in these crusts is 16.0 ± 6.3 mg/cm^2 (95% confidence interval, s = 5.1). The taxonomy of desert lichens is in a confused state and it is probably best to provide a description rather than a tentative identification as stated by Friedmann and Galun: "...the information on lichens in arid zones and desert regions is scarce and scattered. Furthermore, a great number of inadequately researched taxa have received recognition, causing chaos in the nomenclature."[43] The lichens observed consisted of a coccoid green alga and fungal filaments lacking asci throughout the thallus. Dark brown soredia (0.1-1 mm) were produced on white structures 1-10 mm in diameter also lacking asci.

The activity of the lichens is dependent on soil moisture and temperature. No production occurred when the soil was dry. The temperature of the soil crust varied from 60° to 20°C diurnally in June when dry (Tables 7.2-7.5). When wet (2 cm distilled water per day) soil crust temperature varied from 45° to 20°C diurnally and when shaded varied from 35° to 20°C. Thus periods of microbial activity in the soil are determined by moisture and simultaneous cloud cover which reduce the temperature range to small variations at low temperatures. The microbial flora must be heat and desiccation resistant but not necessarily thermophilic.

In addition to cyanobacterial crusts and lichens, bacteria were present and active throughout the site. The density (cells/cm^2) of bacterial

colonizing buried glass slides (incubated from February 18, 1978 to April 8, 1978) was 99,000 ± 18,299 (95% confidence interval, s = 14,000) for sage, 100,000 ± 34,000 (95% confidence interval, s = 27,000) for shinnery oak, and 88,000 ± 10,000 (95% confidence interval, s = 8,000) for barren soil. There were few fungi compared to bacteria. The generation time (h/generation) of bacteria in surface soil was 72.5 ± 1.8 (95% confidence interval, s = 1.8), 72.6 ± 2.8 (95% confidence interval, s = 2.2), and 72.9 ± 1.0 (95% confidence interval, s = 1.0) for sage, shinnery oak, and open soil (Table 7.6).

Laguna Grande de la Sal

The microbial flora of Laguna Grande de la Sal consists of a restricted number of microorganisms due to the strong selective pressure of the saturated salt environment present. Exceptions occur when the salt lake is flooded with fresh water during heavy rains as in the fall of 1978. During this period meromictic stratification developed and the mixolimnion was dominated by *Artemia* sp. (brine shrimp) and a diverse microbial flora. Under normal conditions the concentration of salt is near saturation throughout the lake with the exception of the "Pupfish Spring" area (50,000 ohms) where water enters the lake.

The normal flora of Laguna Grande de la Sal consists of *Dunaliella salina* (a salt alga), *Halobacterium* spp. (halophilic bacteria), and other halophilic organisms including sulfate-reducing bacteria that are as yet undescribed.

Productivity in Laguna Grande was found to be 0.0076 mg Ca CO_3 $l^{-1}h^{-1}$ during spring (April 9, 1978) and 0.4 mg Ca CO_3 l^{-1} h^{-1} during summer (July 1, 1978). In addition the water turned a reddish brown color due to the bloom of *Dunaliella salina* in July of 1978 (see Tables 7.7-7.10).

Pupfish Spring, which feeds Laguna Grande, contains a diverse microbial flora and fauna that was not quantitated due to the limited extent of the spring. It did, however, contain photosynthetic bacteria (*Thiocystis*

sp., purple sulfur bacteria) in a thin purple layer below the calcareous salt crust which surrounds the spring. These were not found in any other site near the WIPP.

Pecos River

The Pecos River is a saline stream fed by numerous salt springs. Conductivity was found to vary from 4,000 to 26,000 from Route 31 to Lower Red Bluff Reservoir. The pH was relatively constant (8.0-8.6). Productivity of phytoplankton varied from 0.1 to 1.5 mg l^{-1} h^{-1} (Tables 7.6 and 7.7) and was due primarily to diatoms. The productivity of extensive Cladophora sp. (macrophyte) beds and epipelon (diatoms present at the surface of sediments) was not determined.

Summary

The characteristics and magnitude of microbial processes underwent preliminary surveys at the WIPP site and also at the Laguna Grande de La Sal and Pecos River sites. Microorganisms were abundant at all of these sites. Pigment analyses and primary production measurements showed that the Pecos River and Laguna Grande de la Sal are eutrophic. Both support high algal densities during the summer months. Laguna Grande de la Sal is anaerobic below 0.5 m and contains sulfide. As a result, it is a potential sink for radionuclides which form sulfide precipitates.

The single most important group of terrestrial microorganisms were the soil lichens, which are present throughout the year. They are not associated with cyanobacteria and presumably do not fix nitrogen.

There are five potential microbial mechanisms by which radionuclides might be mobilized or bioconcentrated in these environments. These include alkylation of radionuclides, formation of radionuclide chelates, reduction of radionuclides, oxidation of radionuclides, and transport of

radionuclides through fungal mycelia to fungal spores which become windborne. Only the latter of these mechanisms has been demonstrated experimentally.[1] As a result, it is impossible to determine the potential effects of microorganisms in soil and water on radionuclide transport even if data on the mass transport of the major elements were available. Present data are insufficient to quantitate any of the biogeochemical cycles.

Table 7.1. Ecosystem compartments and potential biogeochemical processes at and near the WIPP site

Potential Biogeochemical Processes	Ecosystem Compartments										
	Laguna Grande Plankton (mixolimnion)	Laguna Grande Plankton (chemocline)	Laguna Grande Plankton (monimolimnion)	Laguna Grande Sediment	Laguna Grande Salt Crust	Pupfish Spring (crust and sediments)	Pecos River-Plankton	Pecos River-Sediment	Los Medaños--blue-green crust	Los Medaños--lichen crust	Los Medaños--gut flora of arthropods
Nitrification	x	x				x	x		x	x	
Denitrification			x	x				x			x
Auxiliary nitrate reduction			x	x				x			x
Ammonification	x	x	x	x	x	x	x	x	x	x	x
Nitrogen fixation					x	x			x	x	x
Sulfate reduction				x		x		x			
Photosynthetic sulfur oxidation						x					
Chemosynthetic sulfur oxidation		x									
Oxygenic photosynthesis	x	x			x						
Anoxygenic photosynthesis			x		x	x			x		
Aerobic respiration											x
Anaerobic respiration		x	x	x		x		x			x
Alkylation of radionuclides				x		x		x			
Formation of radionuclide chelates	x	x	x	x	x	x	x	x	x	x	x
Degradation of radionuclide chelates	x	x					x		x	x	x
Reduction of radionuclides			x	x	x			x			x
Oxidation of radionuclides	x	x					x		x	x	x

Table 7.2. Soil temperatures for 16 June 1978, open soil, T22S R31E Sec 16.

Temperature Time	Air	10cm depth	Unshaded-2cm rainfall daily	Unshaded	Shaded-2cm rainfall daily	Shaded	Solar radiation (ft. candles)
7:40am	23.7	28.1	23.1	24.6	23.8	23.6	19000
9:00	29.1	28.7	31.1	34.2	28.5	30.5	41000
11:00	33.4	30.6	38.5	48.0	30.0	37.2	42000
1:00	35.9	33.3	38.8	57.8	33.4	40.1	40000
From here on temperature measured more toward surface							
3:00	38.0	36.6	45.2	58.2	35.9	45.0	40000
5:00	39.0	37.1	41.3	51.6	33.8	37.4	39000
7:00	36.1	37.4	31.7	34.1	31.7	34.1	16000
12:00	26.1	32.6	24.1	25.3	23.8	25.7	---

Table 7.3. Soil temperatures for 17 June 1978, open soil, T22S R31E Sec 16.

Temperature Time	Air	10cm depth	Unshaded-2cm rainfall daily	Unshaded	Shaded-2cm rainfall daily	Shaded	Solar radiation (ft. candles)
3:00am	23.7	30.7	21.9	22.6	21.7	23.4	---
7:00	24.6	29.3	22.1	23.5	22.0	24.0	29000
9:00	28.4	29.5	30.8	36.4	26.0	31.4	21000 (cloudy)
11:00	32.5	31.1	41.8	52.0	32.9	38.0	42000
1:00	36.6	32.7	34.1	53.7	33.3	38.6	19500 (95% haze)
3:00	36.1	34.5	44.0	58.6	34.3	35.0	45500 (75% haze)
5:00	38.2	36.1	40.6	49.4	31.8	34.6	40000 (30% haze)
7:00	35.8	37.0	25.8	32.9	27.0	32.7	10000 (hazy)
12:00	26.4	32.2	22.5	24.8	23.2	25.4	---

Table 7.4. Soil temperatures for 18 June 1978, T22S, R31E Sec 16.

Temperature							
Time	Air	Depth	Unshaded-2cm rainfall daily	Unshaded	Shaded-2cm rainfall daily	Shaded	Solar radiation (ft. candles)
3:00	23.6	29.7	20.7	22.2	21.3	23.5	---
7:00	25.1	28.5	21.1	24.0	21.9	23.1	26000 (clear)
9:00	31.7	29.1	29.2	35.6	25.8	29.3	42000 (clear)
11:00	35.3	30.6	38.9	43.6	30.3	38.3	43000
1:00	38.9	31.9	35.4	49.2	30.9	41.9	45000
3:00	35.8	34.8	41.3	59.2	34.1	41.1	45000 (haze on the horizon)
5:00	35.6	35.6	41.6	46.4	28.8	33.6	36000
7:00	31.9	36.8	27.0	30.7	27.6	29.9	700 (thunderhead)
12:00	25.7	32.0	22.7	23.6	23.0	24.7	---

Table 7.5. Soil temperatures for 19 June 1978 T22S R31E Sec 16.

Temperature							
Time	Air	10cm depth	Unshaded-2cm rainfall daily	Unshaded	Shaded-2cm rainfall daily	Shaded	Solar radiation (ft. candles)
3:00	22.5	30.0	20.1	21.0	21.1	22.2	---
7:00	22.4	29.2	21.2	22.6	21.3	22.5	7500 (hazy)
9:00	26.5	28.1	26.6	33.8	24.4	27.3	40000
11:00	32.5	30.5	37.6	49.3	29.8	34.2	45000
1:00	35.0	31.9	41.0	60.8	33.4	40.4	37500
3:00	36.6	35.0	42.0	57.4	34.5	40.4	42000
5:00	36.4	35.6	35.3	37.0	31.2	32.7	37000 (cloudy)
7:00	27.5	35.8	23.8	28.1	23.0	26.8	375
			rained from 7:30-8:15 lightly				
12:00	26.2	28.4	21.7	22.3	21.5	22.8	---

Table 7.6. Density and growth rate of bacteria on glass slides in Los Medaños soil crust (sites 105 sage, 6-10 shinnery oak, 11-15 open soil) T22S R31E Sec. 16.

Site	Cells/cm^2	Hours/generation	Generations/hour
1	126,037	70.9	0.0141
2	98,950	72.5	0.0138
3	128,109	70.9	0.0141
4	83,472	73.5	0.0136
5	58,797	75.8	0.0132
6	100,124	72.5	0.0138
7	50,517	76.92	0.0130
8	81,592	73.5	0.0136
9	113,717	71.4	0.0140
10	157,546	69.4	0.0144
11	89,552	72.9	0.0137
12	105,583	71.9	0.0139
13	87,256	72.9	0.0137
14	93,035	72.5	0.0138
15	65,032	75.2	0.0133

Table 7.7. Aquatic production, 9 April 1978.

Site	Incubation period (h)	Phytoplankton primary production (mg $CaCO_3 \cdot h^{-1} \cdot l^{-1}$) ±95% C.I.	Dissolved organic matter % (excretion/ assimilation x 100)	Temperature (°C)	Conductivity (μ mho)	pH	Total CO_2 (as mg/l$CaCO_3$)
Pecos + 31	4.5	1.55±0.07*	0.8	21	4300	8.6	72.8
	12.5	0.837	0.7				
Black River	4.0	0.118±0.02	4.1	20	4200	8.2	142.0
	12.5	0.826					
Harroun	4.0	0.089±0.007	11.7	21	12000	8.4	161.0
	12.5	0.0588					
Harroun Crossing	4.0	0.1022±0.005	9.7	20	7300	8.5	152.3
	12.5	0.0727					
Malaga Bend	4.5	0.489±0.02	5.4	22	22000	8.3	123.5
	12.5	0.346	4.4				
Pipeline Crossing	4.0	0.372±0.03	4.3	21	26000	8.1	111.8
	12.5	0.293					
Upper Red Bluff Reservoir	4.0	0.301±0.01	4.9	24	17000	8.1	96.6
	12.5	0.269					
Lower Red Bluff Reservoir	4.0	0.1430±0.009	6.2	21	17000	8.1	125.6
	12.5	0.147					
Windmill Stock Tank	4.4	4.20	0.3	19	2000	10.3	198.0
	12.5	4.07	2.3				
Pupfish Spring	4.2	0.043±0.007	37.9	19	60000	7.9	142.8
	12.5	0.040	9.1				
Laguna Grande	4.1	0.076±0.0016		19	>200000	7.0	180.0
	12.5	0.0079					

*95% confidence intervals.

Table 7.8. Aquatic parameters, 25 April 1978.

Samples	n*	Protein (mg/l)	Chlor(a) (mg/l	Chlor(b) (mg/l)
Malaga Bend	50	3.73	22.02	2.12
Station #4-Pecos	50	16.32	7.94	0.775
Station #5-Pecos	100	0.954	4.69	0.871
Windmill	10	25.6	181.6	68.92
Black River-Pecos	50	1.662	9.08	1.721
Harroun #11-Pecos	50	1.642	3.97	0.718
Harround #2-Pecos	50	1.724	3.55	0.346
Pipeline-Pecos	50	5.54	24.68	2.336
Pecos + 31	50	4.50	58.00	14.48
Laguna Grande	50	1.48	8.976	0.263
Pupfish Spring	50	1.76	6.30	0.404

*Sample size.

Table 7.9. Aquatic production, 1 July 1978.

Site	Incubation period (h)	Phytoplankton primary production (mg $CaCO_3 \cdot h^{-1} \cdot l^{-1}$)	Temperature (°C)	Conductivity (μmho's)	pH	Total CO_2 (mg/l$CaCO_3$)
Pecos + 31	4 (lab)	0.649 ±0.0267*	31.5	6,000	8.7	67.6
Malaga Bend	4 (lab)	0.354 ±0.0371	30	30,000	8.3	123.7
Pipeline Crossing	4 (lab)	0.144 ±0.00935	33	23,000	8.6	79.7
Windmill Stock Tank	4 (lab)	0.529 ±0.0516	24	1,700	7.9	173.4
Laguna Grande	7.25 (*in situ*)	0.397 ±0.466	28	Saturated salt >200,000	7.6	123.5

*95% confidence intervals

Table 7:10. Aquatic parameters, 4 February 1978.

	Chlorophyll a (µg/l)	Chlorophyll b (µg/l)	Protein (mg/l)	Phycocyanin (µg/l)	Diatoms (cells/l x 10^{-6})	Bacteria (cells/l x 10^{-9})	Temperature (C)	pH	Conductivity (umhos x 10^{-3})	Alkalinity (mg/l $CaCO_3$)
Pupfish Spring (Laguna Grande De La Sal)	---	---	---	---	---	---	10	7.0	45	---
Windmill Water Tank (WIPP Site)	1.3	0.072	3.6	<10	0.084	2.5	5	8.7	1	160
Pecos River and Highway 31	---	---	---	---	5.7	2.5	11	8.4	4.5	110
Harroun (Pecos River)	15.6	0.24	3.3	<10	1.8	2.3	10	8.2	3.4	130
Pipeline Road (Pecos River)	9.1	0.12	2.3	<10	6.2	0.82	10	8.2	15	120
Red Bluff Reservoir	4.9	0.11	2.6	<10	5.6	2.3	10	8.4	15	100
Subsurface Spring (Laguna Grande De La Sal)	---	---	---	---	---	---	10	7.0	200	---
Solar Pond (Laguna Grande De La Sal)	1.6	0.08	1.2	<10	<0.005	---	15	7.0	>200	---
Subterranean Salt Deposits (WIPP Site) - White	0.13**	---	---	---	---	---	---	---	---	---
Subterranean Salt Deposits (WIPP Site) - Colored	0.10**	---	---	---	---	---	---	---	---	---

*All values are for phytoplankton and exclude epipelon, epilithon, and streamers of macroalgae which were occasionally abundant. Data were collected on 4 February 1978.

**ug/g

Table 7.11 Microbial growth rates--aquatic
In situ growth rates and density of epibacteria on glass slides 15 July 1978.

Site	Cells/cm^2	Generation time (h)
Pipeline	1×10^6	4.8
Pupfish Spring	3.6×10^6	4.4

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CHAPTER 8

THE ARTHROPODS OF THE LOS MEDAÑOS WIPP SITE, WITH EMPHASIS ON THE SOCIAL INSECTS AND SOIL MICROARTHROPODS

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Introduction

Arthropods play a major role in the dynamics of all ecosystems,[1] especially as detritivores in decomposition processes. In any system where soil may be subjected to contaminants, the potential importance of arthropods increases because they may transport soil particles over distances of several meters in the soil column.[2] They ingest soil particles along with organic material and enter major food chains as prey items for vertebrate and invertebrate predators. Consequently, knowledge of arthropod community structure, dynamics, trophic relationships, and effects on rate processes in the system are essential. The studies reported herein represent the initial steps in evaluating the role of various groups of arthropods in the Los Medaños ecosystems (Fig. 8.1). Common and scientific names of arthropods are listed in Table 8.1.

Social insects (ants and termites) are among the most numerous groups of desert arthropods.[3,4] Seed-harvesting ants in arid ecosystems are known to translocate a significant, but not disruptive, fraction of seed production to their subterranean colonies.[4-7] These ants may also be extremely important predators and regulators of energy flow.[4] Termites are essential to litter breakdown, mineral translocation, and soil structuring.[2,8,9,10] On the NMSU Jornada Experimental Ranch, Whitford[4] estimated that termites occur at a density of $1200.m^{-2}$, yielding a biomass of 3 $gm.m^{-2}$. This gives termites the largest standing-crop biomass of any herbivore (for comparison, nearly 10 times greater biomass than current

stocking rates of cattle) on the Jornada Experimental Range. Together with dung beetles (Scarabidae), termites help to break down cattle dung.[10-12]

Arthropods other than social insects have attracted little attention by desert ecologists except for those studies conducted as part of the IBP programs.[13] Studies of insects on oak have demonstrated the effect of oak leaf tannins and nutrients on growth of insects associated with oak. Since shinnery oak (Quercus havardii) is dominant over much of the Los Medanos area, studies of associated arthropod communities could provide good comparisons of this desert oak with oaks in mesic environments.

Microarthropods (mites and collembolans) have received very little attention in desert ecosystem studies[14] but are important to the decomposition processes in forest ecosystems.[15] However, there is speculation that in the desert ecosystems, these organisms significantly affect rates of plant litter breakdown.

Methods

Because of the marked differences in sampling techniques necessary to estimate density, activity, and community composition of the various groups of arthropods, the methods used to study each group are presented under separate subheadings. A complete description of the methods can be found in Whitford, et al.[16]

Ants

The density of small body-size ant colonies was estimated by counting the number of active colonies (identified to species) in randomly placed quadrat frames (15 quadrats in creosotebush area and mesa area and 40 quadrats in the oak-mesquite area). Sampling was done in the early morning and in the evening after sunset to obtain reliable estimates of both nocturnal and diurnal species.[4] Densities of large body-size ants

were obtained by counting all colonies in large fixed 50 x 50 m plots. Plot and quadrat sampling was compared with bait boards[17] to ensure a complete species list (Table 8.1).

Termites

Termite activity was measured using standard bait units (toilet tissue rolls)[9,10] placed on 7 x 7 m grids with 1-m spacing (Fig. 8.2). Five grids were established in the creosote area, mesa area, hummock-mesquite dune, hummock-mesquite interdune, and in the oak-mesquite area. Baits were checked every two weeks in the early morning. Termites present in a bait were counted (the number was estimated if more than 30 of them occupied a bait). Forage consumption was estimated by measuring weight loss of roll and/or by plaster casting.[10] Energy equivalents of paper consumed was calculated using the conversion, 1 g paper = 4.5 kilocalories.[10]

Grasshoppers

Flush transects were used to obtain density estimates of grasshoppers (Table 8.2). Transects were followed by sweep netting to obtain relative percent composition of grasshopper species. Either three or four 100 m x 2 m transects were counted in each area every two weeks until mid-September.

Shrub Insects

Shrub insects were sampled with a D-Vac suction net. Ten shrubs or stem groups of the shinnery oak (*Q. havardii*) and sand sage (*Artemisia filifolia*) were sampled each day the D-Vac machine was operational. If the D-Vac was not operational, shrubs were sampled by sweep net. Samples were stored in vials with ethyl-acetate-impregnated wads and separated from plant parts in the laboratory.

Ground Arthropods

Ground arthropods were sampled using three pitfall trap grids with 15-m trap spacing located as follows: 5 x 5 m grid in mesa area, 7 x 7 m

grid in oak-mesquite area, and 5 x 5 m grid in hummock-mesquite area. Traps were covered with No. 10 cans containing a polypropylene funnel buried flush with the surface. Arthropods were collected in a cup of ethylene glycol. The arthropods were collected from the traps at two-week intervals and stored in large jars of 70% ethanol prior to sorting. Samples were sorted according to order or family, then into species designated by number. Finally, they were oven-dried and weighed.

Soil Microarthropods and Organic Matter Loss

Microarthropods and organic matter loss were studied by a modification of the litter bag technique described by Weigart and Evans.[18] Shinnery oak leaves and mesquite-sand sage leaves and twigs were confined in fiberglass mesh bags (30 g/bag). The bags were air-dried to a constant weight and control-soaked in either distilled water, chlordane insecticide (to eliminate arthropods), or benomyl and captan fungicides (to control fungi) plus chlordane insecticide.

Five replicates of each treatment of shinnery oak litter were placed on the surface under shrubs in an oak-mesquite area; ten replicates were buried at 15 to 20 cm in the same area. Five replicates of each treatment of mesquite-sand sage litter were placed on the surface in a hummock area at the transition with a creosote bush (*Larrea tridentata*) shallow soil area; ten replicates were buried at 15 to 20 cm in this area. The litter bags were left in the field for 45 days, then returned to the laboratory for analysis. Extractions were made of both microarthropods and nematodes. Microarthropods were extracted into water in modified Tullgren funnels from five buried bags and two surface bags of the control group and from two buried bags and one surface bag from each of the experimental groups. Nematodes were extracted from five of each treatment of the buried bags by homogenizing plant litter and passing that material through sieves that extracted the supernatant. The supernatant was then extracted through cotton into water[19] where the nematodes were concentrated for counting. Nematodes were absent from all the randomly checked surface bags. Microarthropods were classed according to species and nematodes were assigned to trophic groups based on esophageal and oral structures.

Loss of organic material from the bags was estimated by ashing bag contents in the muffle furnace and calculating organic content from the equation: $d = IDW + A + (A - y)cf - FDW$, where IDW = initial dry weight of litter, A = ash weight, y = inorganic content of initial litter, cf = correction factor (soil organic fraction ÷ soil inorganic fraction), and d = weight of organic material removed, and FDW = final dry weight.

Soil microarthropods occurring at depths between 0 and 100 cm were extracted by taking 12-cm-diam core samples in the mesa, creosote bush, and oak-mesquite area.

Leaf Damage and Stem Kill, Q. havardii

In September the large numbers of stems of Q. havardii which had been killed were estimated using the step point method. In addition to the 276 stems recorded, a series of 12 were picked at random and returned to the laboratory. Every leaf was removed and the total surface area measured. If the leaf had been attacked by leaf miners, the area mined was measured.

Results

Ants

There was considerable variation in structure of the ant community through time and between habitat types (Tables 8.3-8.5). The Shannon Weaver Species Diversity Index[20] H' was nearly identical among areas: hummock-mesquite H' = 0.73, creosote bush H' = 0.729, and mesa H' = 0.723. The average colony density over the summer was $1111 \cdot ha^{-1}$ in the creosote area, $1088 \cdot ha^{-1}$ in the hummock-mesquite area, and $1285 \cdot ha^{-1}$ in the mesa area. Diurnal activity at bait boards was extended beyond the normal activity period of most species.

The trophic structure of the ant communities was weighted toward the omnivores (Iridomyrmex, Conomyrma and Myrmecocystus); seed harvesters (Pogonomyrmex and Pheidole) occurred in very low abundance in the oak-mesquite area but at moderate densities in the other habitats. Some of

the omnivores were probably foraging in shrubs either to capture insects or to collect honeydew from homopterans (see Table 8.6).

The only nocturnal species was the Mexican honey pot ant (Myrmecocystus mexicanus), which occurred at low densities. Most species were active both during the day and night. The desert harvester ant (Pogonomyrmex desertorum) and Apache harvester ant (Pogonomyrmex apache) were diurnal only.

Termites

Two species of termites were obtained in these studies: Wheeler's termite (Amitermes wheeleri, Family Termitidae) was the most abundant and occurred in all grids; and the Eastern termite (Reticulotermes tibialis, Family Rhinotermitidae), which was found only on grids in the hummock-mesquite area in a few rolls not attacked by A. wheeleri.

Densities were averaged over time at each of the five areas where termites were studied (Table 8.7). These measurements give a very conservative estimate of actual termite populations, since only a small portion of a colony is actively foraging at any given time. No other satisfactory method exists for population sampling of such cryptic organisms.

Paper rolls were sampled twice for weight loss, and the results added to give consumption for the entire season (Table 8.8). These show a much wider range of variation than the population estimates. Most of the variation probably is due to the small size of the grids (49 m^2).

Leaf Damage and Stem Kill, Q. havardii

Leaf damage was assessed on 811 leaves of which 20% had been damaged. This represents a loss of 40% of the leaf-mass-per-unit area mined by leaf miners. A total of 276 stems of Q. havardii were encountered in the pace transit of which 74% were alive, and 69 (or 26%) were dead but with leaves intact (Table 8.9).

Microarthropods

Microarthropod abundance and species diversity were consistently greater in the oak-mesquite area than in either the creosote bush or mesa areas (Tables 8.10 and 8.11). From March to May, the mite community was composed primarily of fungivores and omnivores in all areas. The summer months marked a community shift to predatory families. Some of these, such as Rhodacaridae and Pachylaelapidae, depend on nematodes for much of their food. From mid-July on, cores at depths of 40 to 60 and 80 to 100 cm were taken at each location on the site. No mites were extracted at any time from these depths in any of the three areas with the exception of two Nematalycidae individuals extracted from the 80 to 100 cm depths of the oak-mesquite area on July 13.

Table 8.12 lists total numbers of individuals, per taxon, extracted from two sets of litter bags analyzed during the summer. Over half of the July set of bags was destroyed in the field by the activity of heavy machinery in the area. The only data presented are microarthropod extractions from control or "No Treatment" bags. No microarthropods were extracted from insecticide or fungicide-insecticide treated bags. The communities observed within the buried litter bags included those families extracted from soil cores of the same dates, but also held families not found in the soil extractions. The litter bags provided a concentrated pocket of plant material which served to congregate soil organisms that feed on such debris, as well as those that prey on these oganisms.

Two types of nematodes were found in the soil at the site. These were bacteriovores and fungivores. No nematodes were extracted from surface litter bags (Table 8.13) but these organisms were present in buried bags of all three treatments. From control (NT) and insecticide treated (IT) bags the ratio of bacteriovores to fungivores was determined to be 4:1. This ratio was determined by subsampling and microscopically analyzing the moth parts of the nematodes. The ratio was 2:1 in fungicide-insecticide treated bags of both litter bag sets.

Mean percent organic weight losses for the June 15 litter bag set are presented quantitatively in Table 8.14 and graphically in Figure 8.3. There were highly significant differences among treatment means in both buried and surface bag blocks. An analysis of variance was done for each block and the resulting probabilities for Type I errors are given in Table 8.14. The only complete treatment sets of the July 29 litter bag set that survived field destruction were the NT surface and buried sets in the oak-dune area of the site. Microarthropod counts for these bags are shown in Table 8.12. The mean percent organic weight losses for these treatments are listed in Table 8.14. The July values were very similar to those of the June set.[16]

Discussion

The density of ant colonies and number of species at Los Medaños is less than one-half that of mesquite-mormon tea and creosotebush communities at the Jornada Site (Whitford 1978)[4] and of creosotebush-tar bush communities in eastern Arizona.[17] The lower density and diversity of seed-harvesting ants at Los Medaños when compared with the areas studied by Chew and Whitford is probably related to the density and predictability of annual plants at the WIPP site. Another factor that can affect density and diversity of ants is soil type. The soils in the hummock-mesquite area are sandy and deep; soils in the creosotebush area are silty loams and shallow (depth to caliche 20-40 cm); and soils in the mesa are shallow silty loams. However, since the ant species diversities of those three habitats are the same, it seems unlikely that soils are a factor-affecting diversity.

The activity of ants at bait stations demonstrated that most species were attracted to at least one of the baits. Tuna fish was the most attractive to most of the species. Most species continued foraging at bait stations at temperatures at which they ordinarily cease foraging. This has important implications for foraging theory[21,4] and further suggests that the ant community is food limited.

One ant species, Conomyrma insana, was found regularly in D-Vac samples from shinnery oak and sand sage. This species is primarily a honeydew, exudate feeder but occasionally will take small insects. The relationships between this species and homopteran on shrubs deserves further attention.

The sand dune areas are characterized by the absence of Novomessor cockerelli and occasional widely scattered nests of Pogonomyrmex rugosus. The large colony size, long lived colonies may avoid these areas where blowing sand covers the colony disc. This seems more likely than lack of forage for these two species since forage for these species is available.[4,22]

The densities and estimated rates of cellulose consumption by termites in the Los Medaños area are higher than those reported by Johnson and Whitford[10] for the Jornada area, but similar to densities estimated from the data reported by Haverty et al[9] for southern Arizona. It is not possible to compare these estimated consumption rates to the input of organic detritus since we have no data as yet. With regard to natural foods we have found large termite foraging groups in cow dung pats. In order to evaluate the role of termites in nutrient cycling and energy flow in this system, we will need data on density and rate of cow dung deposition and drying. The extremely high densities of dung beetles taken from the pitfall grids suggest that there may be indirect competitive effects of dung beetles on termites since the beetles remove fresh dung before it dries.

The estimates of densities and biomass of termites are based solely on numbers of termites in the bait roll and consumption of that cellulose material by the termites. Since counts are made only of the forages in a bait roll at the time it is examined, this represents only the foragers from a given termite colony. The fraction of a colony that is foraging at any one time is unknown, therefore, the numbers ranging from 43,000 to 570,000 individuals$\cdot$ha^{-1} represents some unknown fraction of the total number of termites. Hence, all of these data can be interpreted as being conservative estimates.

Comparing the biomass of termites with the other dominant groups of ground arthropods presents an interesting picture. Most of the arthropod biomass is made up of (1) dung feeders - *Scarabidae* (dung beetles) and Isoptera (termites), and (2) detritus feeders - Tenebrionidae (stink beetles) and Spirostrophida (millipedes). Approximately 90% of the ground arthropod biomass on any of the study areas feed on dead plant material or, in the case of the Siliphidae, on dead animal material or dung (Figs. 8.4-8.6). Thus 90% of the arthropod biomass is considered part of the decomposer trophic level of the ecosystem. The low biomass of arthropods on shrubs also suggests that herbage feeders are relatively unimportant in energy flow and nutrient cycling in this ecosystem. The only live plant consumers that achieve densities and biomass of detritivores are the grasshoppers. They were feeding primarily on annual plants and grasses and not on shrub forage. Therefore, shrub biomass production was most directly an input into the detritus food chain.

Although we did not collect the insects, the data on the leaf mining of oak leaves suggest that these insects are important herbivores on Q. havardii. They reduced the mass of leaf material input into the detritus pool and may have left the leaf vulnerable to bacteria and fungi, thus contributing to the decomposition process of the oak leaves.

There are a number of relationships that emerge from the soil core data. There appears to be a seasonal succession in dominant taxa: in the oak-mesquite area, nanorchestid and lordalychid mites were common in spring and early summer but then disappeared and were replaced by pyemotids, rhodacrids, and pachylaelapids. This shift in taxa suggests a change in soil microclimate and, possibly, food. Lordalychids and nanorchestids are primarily fungal feeders but may also be nematode predators. Pyemotids are fungal feeders and the rhodacarids and pachylaelapids are predators.[23] The predators predominated during the warm wet periods and the nanorchestids during the dry periods. Santos et al reported high densities of nanorchestids in June and July in dry soils on the Jornada which suggests that the nanorchestids are probably adapted to dry soils.[14]

The diversity ranking of soil microarthropods in the sequence oak-mesquite > mesa > bush probably reflects the quantity or standing crop of plant litter in those areas and also depth of soil above the caliche. Although the surface soils in the creosotebush area hold more moisture they probably dry faster, as indicated by the shallow caliche layer. The diversity pattern suggests a relationship to plant litter as documented by Santos et al.[14]

The weight losses of oak and mixed litter in 45 days are within the range reported for oak, beech, and other deciduous forest leaves. Bocock and Gilbert reported oak lost 17.4 to 26.2% in six months (January-June) in northern England.[24] Witkamp measured a loss of 53% in white oak (Quercus alba) over one year in Tennessee.[25] The organic weight losses reported in surface litter in this study would probably result in weight loss of 60 to 90% in one year. It is possible to distinguish two age classes of Q. havardii and Prosopis glandulosa leaves on the surface. Therefore, it appears that decomposition rates of surface litter in this ecosystem is comparable to that in southeastern deciduous forests.

There are no data available to compare with weight losses of buried litter. The aeolian nature of the substrate in dune areas makes litter burial a high probability event. Thus, these data are useful for comparisons with surface rates. The high rates of weight loss in buried litter attests to the importance of the entire soil community and moderate environment in organic weight loss.

The marked reduction on weight loss upon treatment with insecticide and the high densities of bacteriophagous and fungivorous nematodes in the insecticide and fungicide-insecticide treatments attest to the importance of microarthropods as regulators of the decomposition process. Freckman et al reported high densities of microbivores in Mojave desert soils.[26] We found higher numbers of microbivorous nematodes in litter treated with insecticide than in non-treated litter. The feeding activity of nematodes can suppress activity of bacteria and fungi and, hence, reduce decomposition rates. This suggests a role for microarthropods not reported previously.[15]

The relationships between the groups of arthropods discussed in this report and the other components of the Los Medanos ecosystems can best be understood by examining the trophic (feeding) relationships between the ecosystem components (Fig. 8.7). The limited data on rates of decomposition of leaf litter suggest that such groups as nematodes, microarthropods, fungi, and bacteria play important roles in turnover (decomposition and mineralization) of a large fraction (probably 50%) of the aboveground productivity of any one year. Other detritivores such as stink beetles (Tenebrionids), termites, and dung beetles (Scarabidae) must process considerable quantities of material as suggested by the high densities and biomass of these taxa. In order to predict rates of turnover, hence the location and rate of movement of radionuclides in such a system, it will be necessary to obtain data not only on numbers of organisms but also on feeding rates, simulation efficiencies, and production of egesta. The trophic relationships depicted in Figure 8.7 are a first step in that process.

Summary

Ant densities and species abundance at the Los Medanos area were nearly 50% lower than Chihuahuan Desert ant communities. Most of the ant species were omnivores; seed harvesters were virtually absent in the dune habitat.

Two subterranean termite species, A. wheeleri and R. tibialis, occurred at densities estimated at 75,000-270,000 ha^{-1} with a live biomass of 160 - 570 g ha^{-1}. These termites consumed an estimated 7-170 kg cellulose ha^{-1} between June and September.

The only important herbivorous insects feeding on live plant tissues were 10 genera of Acrididae and one group of Tettigoniidae grasshoppers occurring at densities from 769 ha^{-1} in creosotebush areas to 2015 ha^{-1} in mesa areas. The most abundant ground arthropods were dung feeders

(Scarabidae), detritus feeders (Tenebrionidae), camel crickets (Gryllacrididae), millipedes (Spirothrophnida), and carrion feeders (Silphidae).

Oak leaf miners attacked 20% of the leaves of Q. havardii, affecting approximately 48% of the leaf area which reduced the mass of the leaf by approximately 40%.

The soil mite community was dominated by fungivores and omnivores in the spring but shifted to families of predatory mites in the summer.

Surface litter decomposition over 45 days of shinnery oak (Q. havardii) and mixed litter (P. glandulosa and A. filifolia) ranged between 9 and 19% while buried litter lost between 57 and 61%. Insecticide treatment reduced buried and surface litter decomposition by approximately 50%.

Removal of mites from litter bags resulted in a doubling of bacterivorous and fungivorous nematodes which by grazing on bacteria and fungi probably reduced the rate of litter decomposition.

Acknowledgments

Perseu F. Santos assisted with microarthropod identification; Robert Parsons assisted with litter bags; Troy McNab of Project Excell measured leaf surface areas and worked up the data on leaf miners; and Sue Bower typed this report.

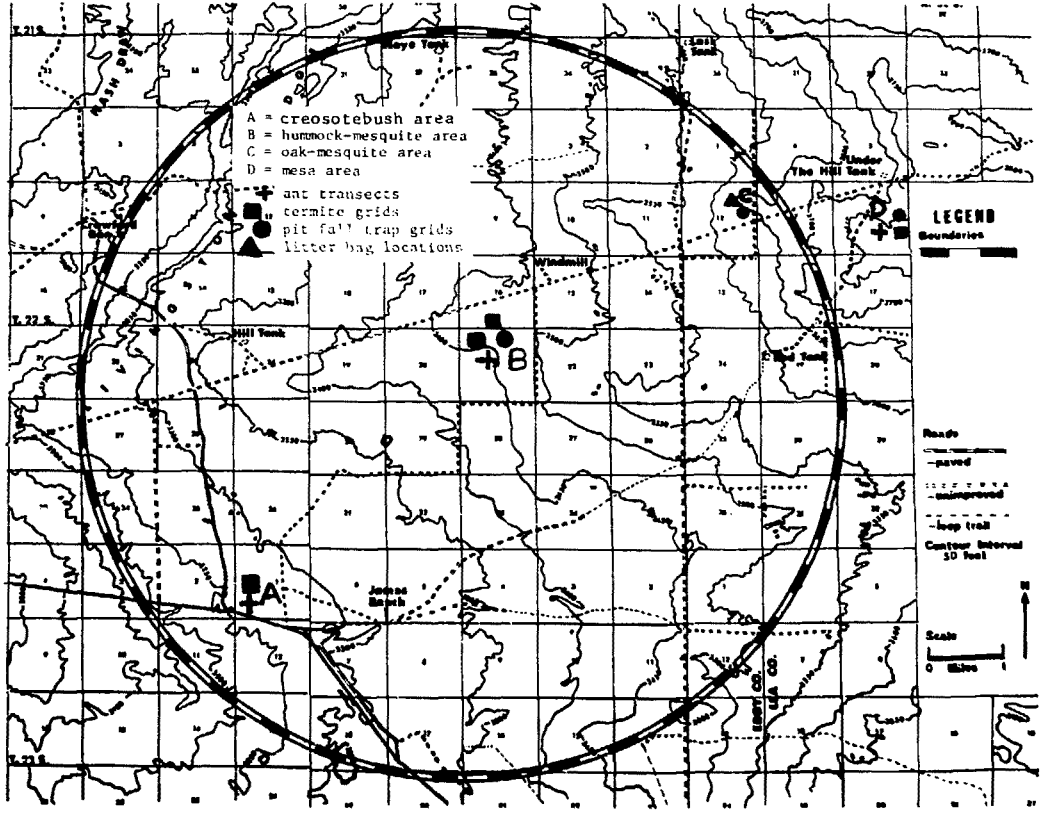

Figure 8.1. Location of study areas for arthropod studies.

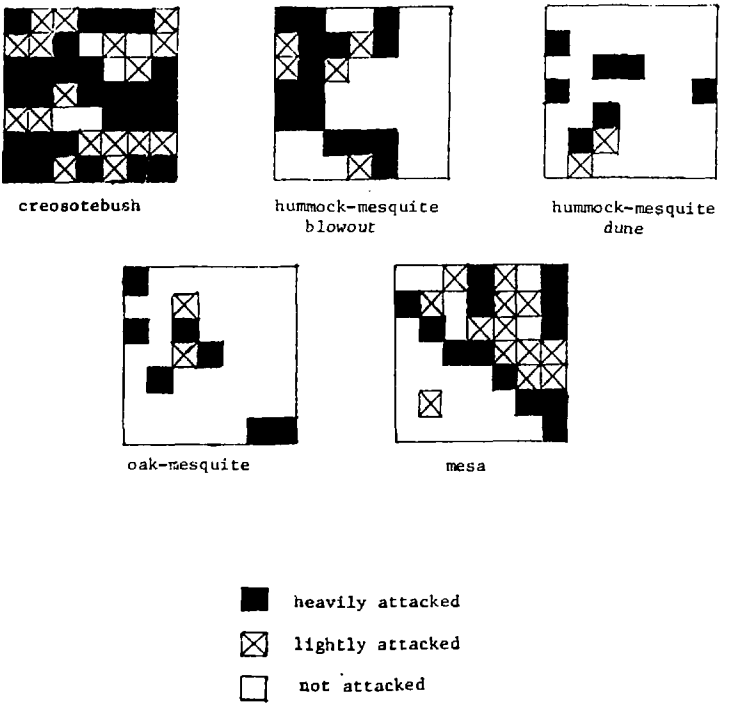

Figure 8.2. The distribution of foraging groups of the subterranean termites on the toilet tissue roll grids as determined by the presence of active foragers throughout the summer of 1978.

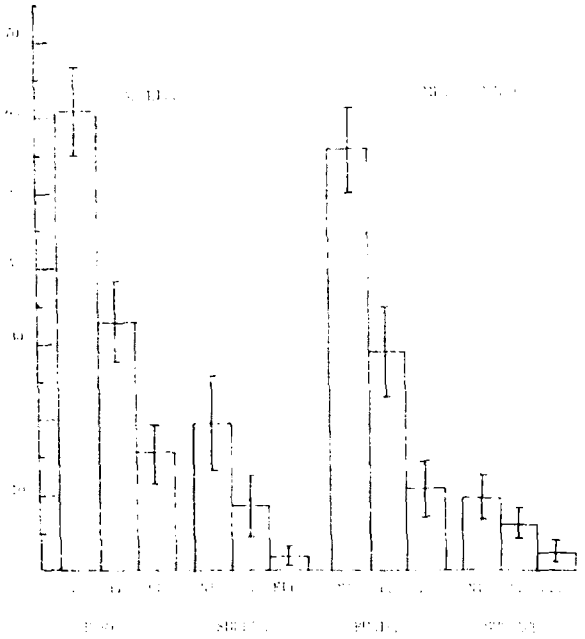

Figure 8.3. Comparison of loss of organic matter of shinnery oak leaves, Quercus havardii, and mixed litter predominantly mesquite, Prosopis glandulosa, and sand sage, Artemisia filifolia, leaves. NT is untreated, IT chlordane insecticide treated and FIT fungicide (benomyl and captan) insecticide (chlordane) treated.

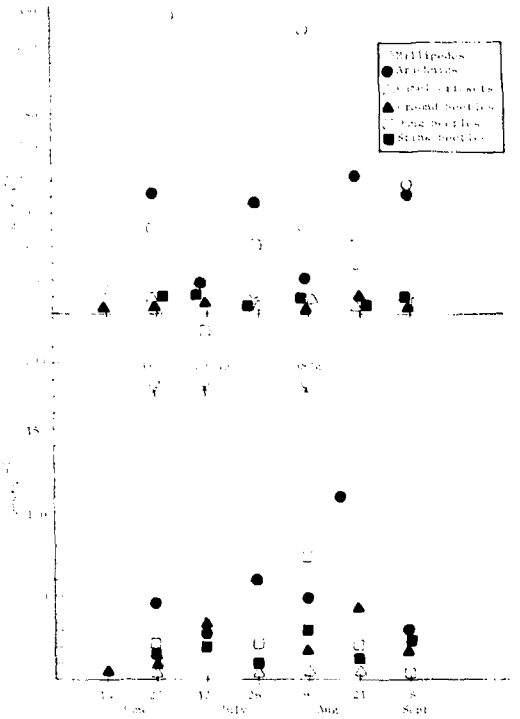

Figure 8.4. Ground arthropods collected in pitfall trap grids in the mesa area. Expressed as numbers and dry biomass per hectare (1978).

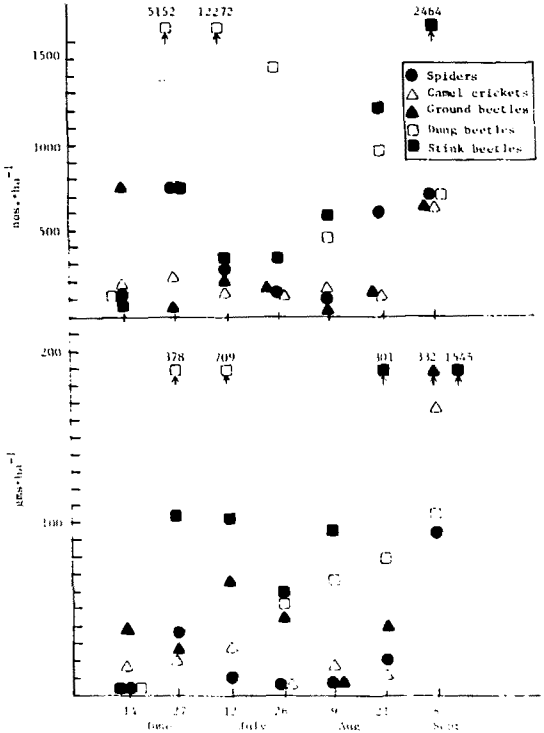

Figure 8.5. Ground arthropods collected in pitfall trap grids in the hummock-mesquite area. Expressed as numbers and dry biomass per hectare (1978).

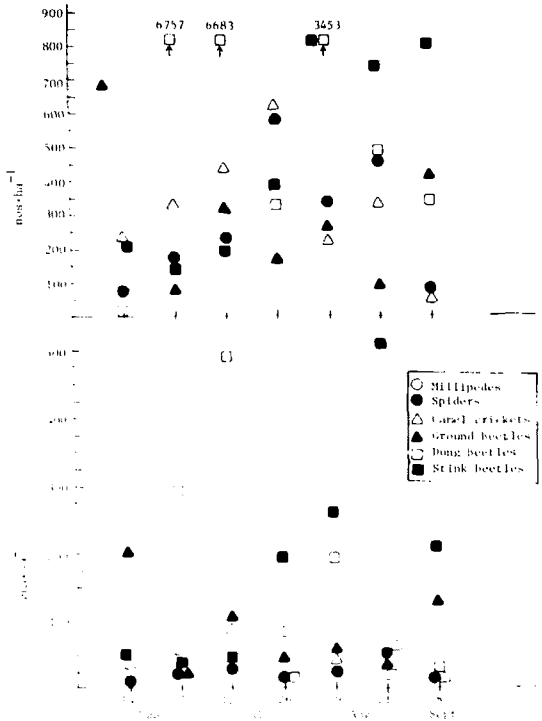

Figure 8.6. Ground arthropods collected in pitfall trap grids in the oak-mesquite area. Expressed as numbers and dry biomass per hectare (1978).

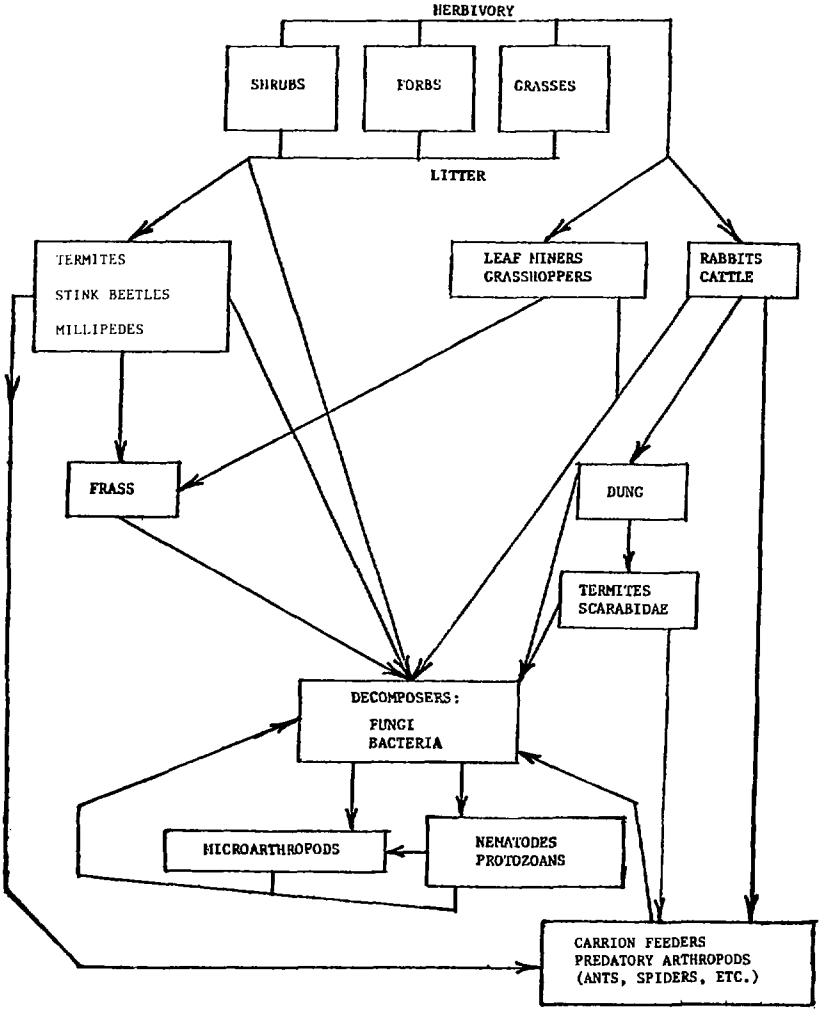

Figure 8.7. The trophic (feeding) relationships of arthropods in the Los Medaños ecosystems. Arrows show the direction of energy and materials flow to the taxa indicated in the boxes.

Table 8.1. A species list of the arthropods found in the Low Medaños area (1978).

ARACHNIDA:	Scorpionida	Scorpions
	Acari	Mites
	Solpugida	Sun-scorpions
	Pedipalpida	Whip-scorpions
	Araneae	Spiders
	Lycosidae	Wolf Spiders
DIPLOPODA:	Spirostrophnida	Millipedes
CHILOPODA:		Centipedes
INSECTA:	Orthoptera	
	Acrididae	Short-horned grasshoppers
	Genera 1	Grey bird locust
	2	Rainbow grasshopper
	3	Plains lubber
	4	Mottled sand grasshopper
	5	Melanoplus grasshopper
	6	Great-crested grasshopper
	7	Arphie grasshopper
	8	Toad lubber
	9	Derotmema grasshopper
	10	Slant-faced grasshopper
	Tettigoniidae	Long-horned grasshopper
	Gryllacrididae	Wingless long-horned grasshoppers
	Gryllidae	Crickets
	Phasmidae	Walking sticks
	Blattidae	Cockroaches
ISOPTERA:	Rhinotermitidae	
	Reticuloterus tibialis	Eastern termites
	Termitidae	
	Amitermes wheeleri	Wheeler's termites
HEMIPTERA:	Reduviidae	Assassin bugs
	Lygaeidae	Seed bugs
HOMOPTERA:	Cicadellidae	Leafhoppers
	Cicadidae	Cicadas
NEUROPTERA:	Chrysopidae	Lace wings
	Myrmeleonitidae	Ant lions

Table 8.1. Continued

COLEOPTERA:	Carabidae	Ground beetles
	Cantharidae	Soldier beetles
	Silphidae	Carrion beetles
	Elateridae	Click beetles
	Histeridae	Hister beetles
	Cincindelidae	Tiger beetles
	Curculionidae	Weevils
	Scarabidae	Dung beetles
	Tenebrionidae	Stink beetles
LEPIDOPTERA:		Butterflies
	Noctuidae	Moths
DIPTERA:	Asilidae	Robber flies
	Sarcophidae	Flesh flies
	Syrphidae	Flower flies
HYMENOPTERA:	Apidae	Bees
	Mutillidae	Velvet ants
	Pompilidae	Spider wasps
	Formicidae	Ants
	Pogonomyrmex rugosus	Rugose harvester ant
	P. apache	Apache harvester ant
	P. desertorum	Desert harvester ant
	Camponotus sp.	Carpenter wood ants
	Pheidole sp.	Thief ants
	Myremcocystus dipilis	Honey ants
	Crematogaster sp.	
	Conomyrma insanum	
	Iridomyrmex prunosum	
	Sphecidae	Sphecid wasps
	Tenthrinidae	Common sunflies
	Braconidae	Braconid wasp

Table 8.2. Densities of grasshoppers based on flush transects in the various areas.

	Area							
	Hummock-Mesquite		Oak-Mesquite		Mesa		Creosote Bush	
Date 78	#/800m^2	#/ha^{-1}	#/800m^2	#/ha^{-1}	#/800m^2	#/ha^{-1}	#/800m^2	#/ha^{-1}
12 July	46	575	110	1375	206	2575	60	750
27 July	76	950	154	1925	156	1950	56	700
9 Aug	47	587	116	1450	162	2025	61	762
22 Aug	53	662	151	1887	162	2025	69	862
8 Sept	96	1200	114	1425	120	1500	ND	ND
Summer Average		795		1612		2015		769

Table 8.3. Estimated densities of ant colonies in the mesa area at the Los Medaños site. Density in number of colonies·ha^{-1} (1978).

Taxon	18 May	30 May	15 June	29 June	13 July	28 July	10 Aug	22 Aug	8 Sept	Summer Average
Crematogaster sp.	4[a]		ND	1000	670	1670	1000[d] 330[e]	330[d] 670[e]		584
Iridomyrmex pruinosum	36[a]	500	ND							67
Myrmecocystus sp.	44[a]		ND	330	330		330[e]			129
Pogonomyrmex rugosus	52[a]		ND	40[a]				0[f]		12
Pogonomyrmex desertorum	4[a]		ND							1
Novomessor cockerelli			ND	12[a]			670[e]	16[f]	330[d]	129
Conomyrma insanum		1500	ND				330[e]			229
Pheidole sp.			ND	330	330		670[d] 670[e]			166

Σ all ants·ha^{-1} = 1088 (summer average)

a - fixed plot counts
d - AM counts with 15 random placements of 1 X 2 m quadrat
e - PM counts with 15 random placements of 1 X 2 m quadrat
f - AM counts on (2) 50 X 50 m plots
ND - not determined

Table 8.4. Estimated densities of ant colonies in the oak-mesquite area at the Los Medaños site. Density in number of colonies·ha^{-1} (1978).

Taxon	18 May	30 May	15 June	29 June	13 July	28 July	10 Aug	22 Aug	8 Sept	Summer Average
Crematogaster sp.	207[a]		ND	1250	500	500	125[b] 125[c]			323
Iridomyrmex pruinosum	58[a]	50	ND	250	750	750	1130[b] 380[c]	380[b] 130[c]	130[b]	437
Myrmecocystus sp.	42[a]		ND	250	250		130[b] 0[c]	330[b] 0[c]	630[b]	210
Pogonomyrmex desertorum	17[a]		ND							2
Pogonomyrmex apache	8[a]		ND						230[b]	30
Conomyrma insanum			ND	1000			250[b] 0[c]	0[b] 130[b]	500[b]	235
Pheidole sp.			ND				380[b] 380[c]			48

Σ all ants·ha^{-1} = 1285 (summer average)

a - fixed plot counts
b - AM counts with 40 random placements of 1 X 2 m quadrat
c - PM counts with 40 random placements of 1 X 2 m quadrat
ND - not determined

Table 8.5. Estimated densities of colonies in the creosotebush area at the Los Medaños site. Density in number of colonies·ha^{-1} (1978).

Taxon	18 May	30 May	15 June	29 June	13 July	28 July	10 Aug	22 Aug	8 Sept	Summer Average
Crematogaster sp.	ND	ND		330	370		1330[d]	330[e]	ND	390
Iridomyrmex pruinosum	ND	ND					330[d]			55
Myrmecoystus dipilis	ND	ND	5.3[g]	12[a]		h		330[d]		70
Myrmecoystus mexicanus	ND	ND	2.6[g]			h				1
Pogonomyrmex rugosus	ND	ND	66[g]	40[a]			10[e]	330[d], 2[f]		74
Pogonomyrmex apache	ND	ND		330						55
Novomessor cockerelli	ND	ND	32[g]	56[a]		h	30[f]	6[f]		21
Conomyrma insanum	ND	ND					670[d], 330[e]			170
Pheidole sp.	ND	ND		330	330	330	330[d]	330[e]		280

a – fixed plot counts
d – AM counts with 15 random placements of 1 X 2 m quadrat
e – PM counts with 15 random placements of 1 X 2 m quadrat
f – AM counts on (2) 50 X 50 m plots
g – point quarter estimate
h – active but not counted
ND– not determined

Σ all ants·ha^{-1} = 1111
summer average

Table 8.6. Shrub insects obtained by D-Vac or sweep net. Numbers are per m^2 of shrub canopy, numbers in parentheses are 10 shrubs swept (1978).

	Sand Sage (*Artemisia filifolia*)							Shinnery Oak (*Quercus havardii*)						
Taxon	23 June	29 June	13 July	27 July	10 Aug	23 Aug	8 Sept	23 June	29 June	13 July	27 July	10 Aug	23 Aug	8 Sept
Arachnida:														
Araneae		2.2		4.8				(2)	1.1		1.1			(2)
Insecta														
Neuroptera:														
Chrysopidae									2.2					
Myrmelionidae	(1)													
Orthoptera:														
Gryllacrididae			1.1											
Gryllidae				0.6										
Acrididae				1.2		0.3		(3)	2.2		1.1			
Coleoptera:														
Circulionidae		2.2		1.2			(1)							
unkeyed				0.6										
Homoptera:														
Cicadellidae				0.6				(1)	2.2		1.1		2.0	
Diptera:														
Syrphidae					1.1							1.1	13.0	
unkeyed											1.1			
Lepidoptera:														
Noctuidae								(2)						
unkeyed						0.3	(1)						2.0	
Hymenoptera:														
Sphecidae	(1)													
Mutillidae				0.6										
Tenthridinidae			1.1			0.3								
Braconidae													2.0	
Formicidae		12.1		2.4	2.2	0.6			3.3			1.1	2.0	(1)
Conomyrma insanum or other											2.2			
unkeyed ant				1.2										

Table 8.7. Density, foraging groups and biomass of termites in the Los Medaños area (1978).

AREA		13 JUNE	28 JUNE	12 JULY	27 JULY	10 AUG	22 AUG	8 SEPT	Summer Average
CREOSOTEBUSH	N	120,000	570,000	410,000	14,000	360,000	320,000	94,000	270,000
	FG	820	820	820	610	820	820	610	760
	BIOMASS	260	1,200	880	30	750	680	200	570
MESA	N	180,000	40,000	60,000	13,000	210,000	0	96,000	100,000
	FG	820	200	410	820	820	0	610	530
	BIOMASS	390	90	130	280	440	0	200	220
HUMMOCK-MESQUITE DUNE	N	90,000	70,000	43,000	43,000	96,000	65,000	120,000	75,000
	FG	410	410	410	410	610	410	610	470
	BIOMASS	190	140	92	90	200	140	240	160
HUMMOCK-MESQUITE BLOW-OUT	N	150,000	360,000	330,000	190,000	180,000	130,000	240,000	230,000
	FG	410	410	610	610	610	610	610	550
	BIOMASS	320	770	710	410	380	280	510	480
OAK-MESQUITE[a,b]	N	-	-	190,000	69,000	110,000	-	-	120,000
	FG	-	-	610	610	610	-	-	610
	BIOMASS	-	-	420	150	240	-	-	270

N = number·ha^{-1}
FG = foraging groups·ha^{-1}
BIOMASS = livegrams·ha^{-1}
a = grid 6-28-78
b = trampled by grazing cows before 8-27-78

Table 8.8. Cellulose consumption of termites in the Los Medaños area.

AREA	COLLECTION DATE	TOTAL CONSUMPTION $kg \cdot ha^{-1}$	ENERGY CONSUMPTION $kcal \cdot ha^{-1}$
CREOSOTEBUSH[a]	13 August 1978	90.65	
	8 Sept 1978	78.89	
	Summer total	169.54	763,000
MESA[a]	13 August 1978	25.53	
	8 Sept 1978	-0-[d]	
	Summer total	25.53	114,000
HUMMOCK MESQUITE DUNE[a]	13 August 1978	-0-[e]	
	8 Sept 1978	20.18	
	Summer total	20.18	91,000
HUMMOCK MESQUITE BLOW-OUT[a]	13 August 1978	35.06	
	8 Sept 1978	31.12	
	Summer total	66.18	298,000
OAK-MESQUITE[b]	13 August 1978	6.96	
	8 Sept 1978	-0-[f]	
	Summer total	6.96	31,300

a - grid set in place 5 June 1978
b - grid set in place 28 June 1978
c - based on conversion 1 gram = 4.5 kcal
d - weight of "eaten" rolls not significantly different from weight of "uneaten" rolls
e - on first sampling date, 10 rolls were taken at random from each grid in this case, no eaten rolls were taken
f - grid trampled by cows, data not recordable

Table 8.9. Leaf damage and stem kill of shinnery oak, Los Medaños site (1978).

Leaf area	average	2.9 ± 1.4 cm^2
	range	$0.48 - 7.77$ cm^2
Mined area	average	1.4 ± 1.1 cm^2
	range	$0.04 - 5.56$ cm^2
Leaf weight	0.01749 $gm \cdot cm^{-2}$	(n = 6)
Mined leaf weight	0.01053 $gm \cdot cm^{-2}$	(n = 6)
	Mined leaves show 40% weight loss	
Stem kill	n = 276	69 (26%) dead
		207 (74%) alive

Table 8.10. Families and relative abundances of microarthropods extracted from soil cores taken in the oak-mesquite area. Core depths - 0-20 cm (1978).

Family and Suborder	Core Date						
	27 Mar	22 Apr	16 Jun	29 Jun	13 Jul	10 Aug	12 Sep
Prostigmata:							
Lordalychidae	C	R	-	-	-	-	-
Nanorchestidae	R	R	VR	VR	-	-	-
Tetranychidae	VR	VR	-	-	-	-	-
Pyemotidae	-	-	VR	R	C	R	VR
Bdellidae	-	-	-	-	VR	VR	-
Anystidae	-	-	-	-	VR	VR	VR
Paratydeidae	-	-	-	-	-	VR	-
Linotetranidae	-	-	-	-	-	R	C
Stigmaeidae	-	-	-	-	-	VR	R
Astigmata:							
Unidentified (Immature)	-	-	-	-	-	-	VR
Oribatid Infer.:							
Unidentified	-	-	-	-	-	VR	-
Mesostigmata:							
Rhodacaridae	-	-	VR	R	C	D	C
Pachylaelapidae	-	-	VR	VR	R	C	R
Collembola	-	-	R	VR	-	VR	-
Insect Larvae	-	-	VR	VR	VR	-	-

Dominance Value Code:
- - = 0/core
- VR = Very Rare = 1-5/core
- R = Rare = 6-10/core
- C = Common = 11-50/core
- D = Dominant = 50 or more/core

Table 8.11. Families and relative abundances of microarthropods extracted from soil cores taken in the creosote and mesa areas. Core depths = 0-20 cm.

CREOSOTE AREA

Family and Suborder	Core Date 22 Apr	16 Jun	29 Jun	13 Jul
Prostigmata:				
Nanorchestidae	R	-	-	-
Tetranychidae	VR	-	-	-
Collembola	-	-	VR	VR

MESA AREA

Family and Suborder	Core Date 22 Apr	16 Jun	29 Jun	13 Jul	12 Sep
Prostigmata:					
Lordalychidae	R	-	-	-	-
Nanorchestidae	VR	-	-	-	-
Tetranychidae	VR	-	-	-	-
Pyemotidae	-	-	-	R	R
Linotetranidae	-	-	-	-	R
Bdellidae	-	-	-	-	VR
Oribatid Infer.:					
Unidentified	-	-	-	R	C
Astigmata:					
Unidentified (Immature)	-	-	-	VR	C
Mesostigmata:					
Rhodacaridae	-	-	-	-	VR

Dominance Value Code: - = 0/core
VR = Very Rare = 1-5/core
R = Rare = 6-10/core
C = Common = 11-50/core

Table 8.12. Survey of microarthropod families and abundances from No Treatment (NT) litter bags. Data include litter bag sets of 15 June and 29 July. All numbers represent total counts from five extracted litter bags (1978).

SURFACE BAGS

Family and Suborder	15 June		29 July
	Oak-Litter	Mixed Litter	Oak-litter
Prostigmata:			
Bdellidae	10	5	7
Nanorchestidae	2	0	0
Trombidiodea	3	4	6
Podapolipidae	1	0	0
Raphignathidae	1	0	0
Scutacaridae	5	4	3
Tarsonemidae	12	6	27
Pyemotidae	5	3	2
Anystidae	4	1	9
Caligonaellidae	0	3	0
Stigmaeidae	0	1	2
Astigmata:			
Acaridae	18	11	10
Oribatid Super.	10	8	0
Oribatid Infer.	5	4	26
Collembola	9	3	5
Insect larvae	0	1	1

BURIED BAGS

Family and Suborder	15 June		29 July
	Oak-litter	Mixed Litter	Oak-litter
Prostigmata:			
Nanorchestidae	5	0	0
Raphignathidae	0	0	1
Mesostigmata:			
Rhodacaridae	384	353	421
Pachylaelapidae	168	102	212
Astigmata:			
Acaridae	103	29	75
Insect Larvae	3	7	1

Table 8.13. Number of nematodes extracted from 15 June and 29 July litter bag sets. Values are mean numbers per bag (1978).

15 JUNE BAGS

SURFACE: (Two randomly selected bags from each treatment)

	Mesquite	Hummock-Mesquite
No Treatment (NT)	0	0
Insecticide Treatment (IT)	0	0
Fungicide-Insecticide Treatment (FIT)	0	0

BURIED: (Five bags from each treatment)

	Mesquite	Hummock-Mesquite
No Treatment (NT)	155	54
Insecticide Treatment (IT)	420	78
Fungicide-Insecticide Treatment (FIT)	211	20

29 JULY BAGS

SURFACE: (Two randomly selected bags from each treatment)

	Mesquite	Hummock-Mesquite
No Treatment (NT)	0	Lost in Field
Insecticide Treatment (IT)	0	
Fungicide-Insecticide Treatment (FIT)	0	

BURIED: (Five bags from each treatment)

	Mesquite	Hummock-Mesquite
No Treatment (NT)	235	Lost in Field
Insecticide Treatment (IT)	470	
Fungicide-Insecticide Treatment (FIT)	207	

Table 8.14. Mean percent weight losses for litter bag treatments. Data for 15 June bag set and 29 July "No Treatment" block. Values represent mean ± one standard deviation of the percent organic weight loss/bag. Five bags/treatment are included in calculating means. Probability of Type I error is given for each Anova block.

OAK LITTER BAGS: 15 June		
BURIED---	No Treatment	61.45 ± 7.87
	Insecticide Treatment	33.31 ± 5.33
	Fungicide-Insecticide Treatment	23.25 ± 1.87
	F = 62.65 Prob. = .00001	
SURFACE--	No Treatment	19.11 ± 6.69
	Insecticide Treatment	8.07 ± 3.82
	Fungicide-Insecticide Treatment	1.21 ± 1.60
	F = 11.38 Prob. = .0048	
MIXED LITTER BAGS: 15 June		
BURIED---	No Treatment	56.19 ± 5.69
	Insecticide Treatment	28.14 ± 5.47
	Fungicide-Insecticide Treatment	10.99 ± 3.81
	F = 90.11 Prob. = .00001	
SURFACE--	No Treatment	9.01 ± 3.18
	Insecticide Treatment	5.75 ± 1.84
	Fungicide-Insecticide Treatment	2.21 ± 1.60
	F = 8.64 Prob. = .0057	
OAK LITTER BAGS (NO TREATMENT ONLY): 29 July		
BURIED NT		57.31 ± 3.82
SURFACE NT		11.85 ± 2.99

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CHAPTER 9

DENSITIES AND SPECIES COMPOSITION OF THE AVIFAUNA OF THE LOS MEDAÑOS WIPP SITE, SOUTHEASTERN NEW MEXICO

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Introduction

Few published works deal with breeding bird densities of the arid regions of the southwestern U.S. Hensley[1] and Tomoff[2] studied the composition and diversity of avian species in the Sonoran Desert of southern Arizona. Dixon investigated desert scrub birds in the Big Bend region of western Texas,[3] and Raitt and Maze studied species composition and densities of breeding birds in a creosotebush community in southern New Mexico.[4] Here we describe the avian species composition and densities of four habitat types on the WIPP site in Lea and Eddy Counties, southeastern New Mexico, during the late spring and summer of 1978.

Data gathered over several years on the reproductive success of several of the characteristic bird species, and growth rates of nestlings eventually will permit us to recognize the effects of year-to-year variation in climatic factors affecting reproductive success, especially rainfall, and will provide a picture of the impact of predation. This knowledge will in turn allow us to determine the range of normal annual variation in reproductive output in the avian species of this region.

Materials and Methods

Study Sites and Vegetational Analyses

Study sites were established in four distinct habitat types: mesquite-shinnery oak, mesquite-short grassland, creosotebush, and hummock-mesquite

(clusters of shrubby mesquite on sand hummocks) (Fig. 9.1). We set up a 9-ha grid (300 m x 300 m) and a separate 610-m census line in each of the first three habitat types. In the hummock-mesquite, two 610-m census lines were established because of the extreme difficulty of laying out a square grid. Although we attempted to place the study plots in uniform habitat, some intra-grid vegetational variation does exist.*

The point quarter method was used[5] to determine shrub density, relative shrub density by species, cover, relative cover, frequency and relative frequency on each 9-ha grid. Each 50-m stake (n = 49) was used as a point, with a fiftieth point selected randomly. At each point, two 1-m sticks were laid down at right angles to form the four quarters. At the tip of each meter stick, ground cover (bare ground, litter, grasses, or forbs) was recorded. In each quarter, the distance from the stick to the center of the closest shrub was measured and for each shrub the following data were collected: species, distance, height at center, greatest length, and greatest width. In addition, a 1.5-m stick marked off in 10-cm intervals was used to determine a foliage height profile of the measured shrub. The stick was placed vertically at the center of each shrub and the heights (0-10 cm, 10-20 cm, 20-30 cm, etc) were recorded at the points where foliage touched the stick.

Russ Pettit, of Texas Tech University, and his colleagues conducted the vegetational analysis along the five transects (see Ch. 7 for their methods). The technique they employed tends to underestimate the density of large shrubs in some cases (e.g., mesquite) and to overestimate the density of small shrubs (e.g., creosotebush, Condalia sp.).

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*Grid locations: Mesquite-shinnery oak--T22S R31E Sec 22, NE 1/4; mesquite grassland--T22S R31E Sec 9, SE 1/4; creosotebush--T23S R30E Sec 34, NE 1/4. Transect line locations: mesquite-shinnery oak--T22S R31E Sec 22, NE 1/4; mesquite-grassland--T22S R32E Sec 9, NE 1/4; creosote bush--T23S R30E Sec 35, NW 1/4; hummock-mesquite #1--T23S R31E Sec 4, NE 1/4; #2--T23S R31E Sec 4 and 5, W 1/2 and E 1/2.

Roadside Censuses

To determine annual fluctuations in species diversity and relative abundance on the WIPP site we expanded the 9 original survey sites in the 4-sq-mi area around ERDA 9 to 50 in May 1978. The original 9 sites were retained. This 25-sq-mi area (census stops at 0.5-mi intervals) includes the major habitat types of mesquite-shinnery oak, creosotebush, hummock-mesquite, in addition to localized transition types such as mesquite-sagebrush, mesquite-snakeweed, sage-shinnery oak, and pure mesquite. The roadside census includes no mesquite-grassland habitat.

This transect is run at monthly intervals throughout the year, following the procedure of the U.S. Fish and Wildlife Breeding Bird Census. Starting one-half hour before sunrise, three minutes are spent at each of the 50 stops, recording all birds seen or heard within a one-fourth-mile radius. Temperature, sky, and wind conditions are recorded at the beginning and end of the run.

Population Densities and Territory Sizes

The 9-ha plots (with grids at 50-m intervals) were used to determine densities of breeding birds and territory sizes. The 610-m transect lines served to determine densities of all bird species present, both breeders and nonbreeders. These transects were divided into ten 61-m sections. At each 61-m marker, lines were set up on both sides of the main transect, with markers 15.2, 30.5, 61.0, 122.0, and 244.0 m from the census route. These were used to estimate the distance of an observed bird from the transect lines.

Dominant vegetation on the 9-ha grids was mapped on graph paper. At the beginning and end of the study (early May to late July), territories of breeding birds were mapped by following singing or displaying males.[6] Territory size was then determined by using a planimeter and expressed in hectares. Density-per-species was determined by the number of territories per 9 ha, assuming that the birds were monogamous. Birds on the grid, but with no defined territory, were also recorded. Whether these birds bred

is unknown, but since they utilized the grid they were included when total densities were determined.

The 610-m transects[7] were run twice monthly beginning at sunrise. We recorded all birds detected by sight or sound as we walked. Also recorded was the approximate distance along the transect (0-15, 15-30, 30-61, 61-122, 122-244 m) at which the bird was first detected and whether it was first seen or heard. After walking the census, 10 to 15 min were allowed to elapse before the census was walked a second time. All censuses were totalled at the end of the summer and a coefficient of detectability determined.[6,7] The total number of birds seen was adjusted using this coefficient of detectability. Because most birds recorded were males (often vocally defending territories), the adjusted total was multiplied by two to account for the less conspicuous incubating or brooding females. The final density is then expressed as individuals per square kilometer.

Nest Location and Success

Active nests were located by watching the behavior of birds (carrying nest material, food, foraging, etc.), by flushing incubating females, and by checking all conspicuous nests, e.g., those of ravens and cactus wrens. For each nest the site, height, construction materials, and locations were recorded. Nests were checked once a week or more to determine clutch size, the incubation period, and predation. After the eggs had hatched, nests were checked three times a week and the nestlings weighed to determine growth rates. Nests were checked until young disappeared or fledged to determine nesting success.

Results

Vegetation of the Study Areas

Vegetational analyses of the eight study areas (three grids and five transects) are presented in Tables 9.1, 9.2, and 9.3. In the mesquite-shinnery oak habitat, the oak (*Quercus havardii*) is the dominant shrub. Oaks are of uniform height, and little vegetational relief exists in this

habitat. The mesquite shrubs (Prosopis glandulosa) provide nest sites for shrub-nesting birds. The high percentage of bare ground, along with the sparcity of grass and forb cover, is apparently not conducive to ground nesting.

Mesquite grassland is composed predominantly of low mesquite shrubs (less than 1 m tall), interrupted by thick groves of taller mesquites up to 3 m in height. These provide favorable nesting sites for many bird species. The high grass and forbs also provide satisfactory cover for some ground nesting species.

The creosotebush study site is composed predominantly of creosotebush (Larrea tridentata), with tall mesquite thickets in shallow depressions that collect more moisture than surrounding areas. Aside from these mesquite thickets, the creosotebush area is uniform in height and distribution of creosote.

The two hummock-mesquite areas are perhaps the most variable habitat types. Large clumps of mesquite predominate, with single trees up to 5 m tall; areas of pure shinnery oak and bare sand dunes are also present. The diversity and complexity of this habitat provide a variety of nesting sites. More habitat variation exists on the first hummock-mesquite transect than on the second.

Checklist

A total of 88 species of birds representing 31 families has been seen on or near the WIPP site (Table 9.4). Sixteen of the 88 species were recorded on the nearby salt lakes beside New Mexico Highway 128 or at the intersection of the Pecos River and New Mexico Highway 31. Seventeen species new to the list were added during the 1978 field season.

Relative Density and Diversity

Tables 9.5 and 9.6 show the results of the monthly roadside censuses. Because the procedures followed during December through April differed from those used May through September, results from these 2 time blocks

are presented separately. Both the number of species and the number of individuals were greatest in May and June as spring migrants passed through the area and resident species conspicuously moved about prior to establishing territories. The diversity and density of birds decreased in July and August, with only breeding species recorded. In September, the species numbers again increased as some fall migrants moved into the area.

Densities of Breeding Birds

Densities of the 27 breeding species recorded along the Emlen transects are listed in Table 9.7. Ten additional species were probably bred in the WIPP area but were not recorded on any of the transects. These are Turkey Vulture, Red-tailed Hawk, Harris Hawk, Golden Eagle (an immature eagle was seen in July), Lesser Prairie Chicken, Roadrunner, Burrowing Owl, Poor-will, House Sparrow, and House Finch.

The greatest diversity (18 species) and density (438.4 individuals per square km) of breeding birds was in the first hummock-mesquite area where habitat diversity was greatest. The lowest density of breeding birds was in mesquite-shinnery oak. Seventeen species were recorded in this area, but all were scarce. The lowest diversity of breeding birds was in the creosote area; however, density was high, due primarily to one species, the Black-throated Sparrow, which alone accounted for 54% of the total density. The mesquite-grassland habitat supported 17 breeding species, all of which were present in relatively low densities. Overall, Black-throated Sparrows provided 50% of the total diversity.

The 9-ha grids were designed primarily to determine territory sizes; they were not large enough to satisfactorily sample densities. Therefore, to avoid artificial accuracy, densities are presented as individuals per 9 ha, rather than extrapolated to individuals per square kilometers. Densities and territory sizes are given in Table 9.8. Mesquite grassland had the highest species diversity and density, followed by creosotebush and mesquite-shinnery oak.

Nest Success

Table 9.9 lists all nests found during the summer of 1978, along with details of location and nest materials. Table 9.10 summarizes their fates. Of the 36 nests found in 1978, we had sufficient data to determine success for only 21 (58%). Overall success was 33%. Passerine nesting success was 27%, but was slightly lower (24%) when White-necked Ravens were excluded. The ravens had an overall success of 32%. Ash-throated Flycatchers and Ladder-backed Woodpeckers successfully reared young, but we could not calculate the percent of success because clutch sizes were unknown.

Our data indicate that the Roadrunner was the most successful nesting species. Two of the three pairs (the third was found at the end of a nesting cycle) successfully reared full clutches of five and seven.

Although nest failure was high, the role of predation is unknown. Some of the Cactus Wren nests appeared to be predated because they had been torn open and the eggs and/or young apparently removed. Most failed nests were empty but were not damaged. Several White-necked Raven eggs were addled, but these remained in the nest after others had disappeared. We suspect that snakes are important predators. Coachwhips (*Masticophis flagellum*) are the most commonly seen snakes in the study area and are reportedly excellent tree climbers and predators of the contents of bird nests.

Growth patterns were obtained for 12 young in 2 Roadrunner nests and 8 young in 2 White-necked Raven nests (Tables 9.11 and 9.12). Data were insufficient to determine growth in other species.

Discussion

Population Density

We were somewhat surprised that the mesquite-shinnery oak habitat yielded such low densities compared to all other habitats censused (Table

9.7). Differences in species diversity do not explain these patterns. Rather, a very few species account for the great variation. The Black-throated Sparrow alone makes up 54% in the hummock-mesquite area No. 1, and 37% in the hummock-mesquite area No. 2. In contrast, this species accounts for only 7.7% of the species density in the mesquite-shinnery oak area. Raitt and Maze[4] likewise found Black-throated Sparrows to be by far the most common species in the creosotebush community they studied. No species exists at higher diversities in the mesquite-shinnery oak than in other habitats; in fact, this area appears to be a stronghold of only one species, the Western Meadowlark.

The cavity-nesting Ladder-backed Woodpecker and Ash-throated Flycatcher were recorded only in the mesquite-grassland and the two hummock-mesquite areas. Significantly, only these sites contain trees large enough for the woodpeckers to excavate cavities in.

Several species were recorded in all habitats (Scaled Quail, Cactus Wren, Loggerhead Shrike, Brown-headed Cowbird, and Pyrrhuloxia). These species are very different ecologically and it is not immediately apparent what characteristics they share that makes for their broad ecological tolerances. Loggerhead Shrikes and Brown-headed Cowbirds are extremely widespread on a continental scale, whereas the others are restricted to the southwestern U.S. and northern Mexico.

Faunistic Comparisons

In comparing the breeding species compositions of our study sites with those of Raitt and Maze,[4] Dixon,[5] and Hensley,[1] we find that only Mourning Doves, Loggerhead Shrikes, and Black-throated Sparrows are common to all four desert regions. Overall, the species diversity on the WIPP site is comparable to other arid southwestern study areas. However, the species composition is somewhat different in that midwestern or Great Plains components, although absent in the other areas, are present here: e.g., Bobwhite Quail, Scissor-tailed Flycatcher, Eastern Meadowlark.

The avifauna on the study area is perhaps most distinctive in terms of the faunal mix--Bobwhite and Scaled Quail, the three species of mimids, and the two meadowlarks. No breeding species recorded is particularly limited overall, either geographically or ecologically. All occur over very large areas and several are essentially continent-wide in their distributions: Mourning Dove, Barn Swallow, Mockingbird, Loggerhead Shrike, Northern Oriole, and Brown-headed Cowbird.

Many of the species recorded (Table 9.4) are migrants through the area, or are only present as winter residents. Typically, these are present only for relatively brief periods in the spring and/or fall, or are present in low densities during the winter months. Of the 27 probable breeding species listed in Table 9.7, more than half migrate out of the area in late summer and autumn. Thus winter species diversity is considerably less than summer diversity (Table 9.5).

Human Usage of Birds

An important consideration with regard to the avifauna is the taking of game birds by man for sport and food. Two species, Mourning Doves and Scaled Quail, comprise the great majority of birds taken by hunters, with Lesser Prairie Chickens being far less significant in this regard. Tables 9.13, 9.14, and 9.15 provide information on the total harvests of these species over the past 11 years in Eddy and Lea counties. The large numbers of doves and quail taken clearly indicate that these game birds represent an important "pathway to man".

Summary

We employed several procedures to study avian species diversity and density on the Los Medaños WIPP site. To obtain a picture of overall species diversity throughout the year, we undertook roadside censuses at monthly intervals. To estimate population densities and territory sizes, we established 9-ha grids in three distinctive habitat types: mesquite-shinnery oak, mesquite grassland, and creosotebush. We also established

610-m linear transects to determine population densities. One transect, located near each of the corresponding grids, was placed in the mesquite-shinnery oak, mesquite-grassland, and creosotebush habitats. In addition, two transect lines were run through the hummock-mesquite habitat. Detailed vegetational analyses were conducted at all of these sites.

Overall, 88 species of birds representing 31 families have been seen on or near the WIPP site. Seventeen of these were added during the summer of 1978. Numbers recorded during the monthly roadside censuses waxed and waned seasonally, as might be expected. This is due to the conspicuous influx of migrants and summer residents in spring and the departure of breeding species in late summer. Moreover, seasonal differences in the conspicuousness of many birds contribute to the variation in numbers of individuals and species recorded.

By and large, breeding bird densities were not high, with one notable exception. Black-throated Sparrows are strikingly abundant on most study sites as compared both to any other single species and to all other species combined.

Densities and diversity of breeding species are comparable to those found in other desert regions. The presence of a midwestern or Great Plains component in the avifauna distinguishes the WIPP site from other arid southwestern areas that have been studied. This species mix, rather than the presence of any particular species, appears to be the most unusual aspect of the avifauna of the WIPP site.

Acknowledgments

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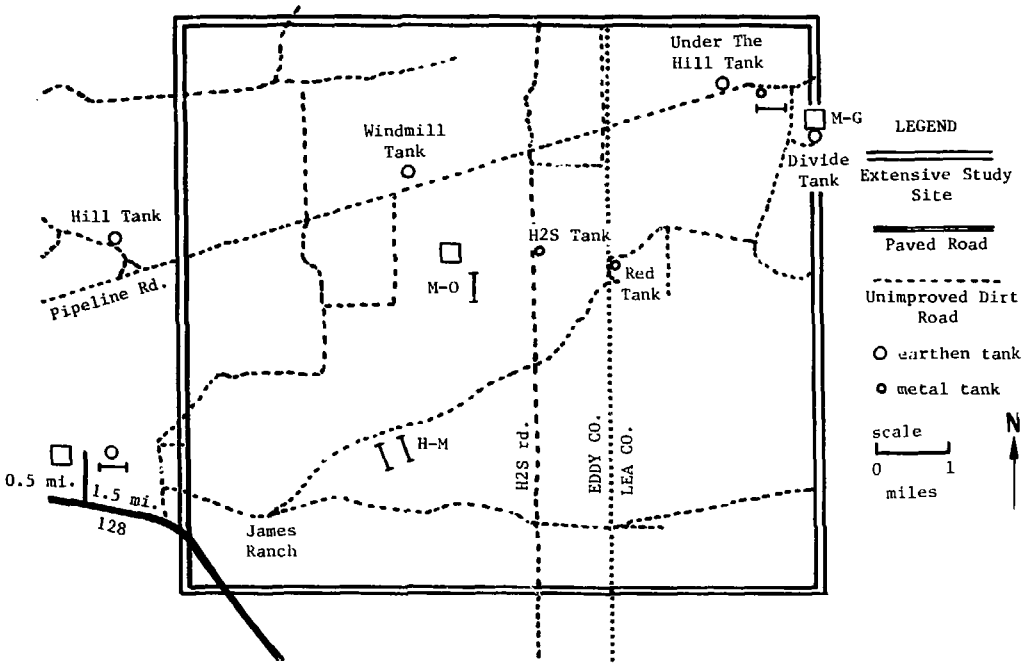

Figure 9.1. Map of the Los Medaños Study Area Showing Bird Grids and Transects.

Table 9.1. Vegetational analysis of three 9.0-ha grids.

Species (n)		Density of shrubs ha.	Relative density by species	Cover m^2/ha.	Relative cover by species	Frequency %	Relative frequency by species	Average height m	Importance value by species*
Mesquite-shinnery oak									
Artemisia filifolia	(44)	[illegible]	[illegible]	14.9	6.4	[illegible]	[illegible]	[illegible]	[illegible]
Opuntia sp.	(2)	3.4	[illegible]	.3	.1	[illegible]	1.6	[illegible]	[illegible]
Prosopis glandulosa	(3)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.1	1.42	[illegible]
Quercus havardii		[illegible]	[illegible]	1,435.	65.	[illegible]	[illegible]	[illegible]	[illegible]
Yucca campestris	(1)	341.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.3	[illegible]	43.[illegible]
Total		[illegible],645.	[illegible]	2,227.[illegible]	[illegible]	244.[illegible]	[illegible]	[illegible]	[illegible]
Mesquite-grassland									
Condalia sp.	(2)	[illegible]	[illegible]	1.43	[illegible]	[illegible]	3.3	[illegible]	4.4[illegible]
Larrea tridentata	(1)	4.8	[illegible]	[illegible].24	0.01	[illegible]	1.7	0.07	2.2[illegible]
Opuntia sp.	(7)	33.3	3.5	9.32	0.5[illegible]	12.[illegible]	[illegible]	0.35	14.5%
Prosopis glandulosa	(189)	899.[illegible]	94.3	1,681.5	99.2[illegible]	[illegible]	83.3	0.72	277.0%
Yucca campestris	(1)	4.[illegible]	[illegible]	2.88	0.1[illegible]	[illegible]	1.7	0.69	2.4%
Total	(2[illegible])	951.[illegible]	[illegible]	1,695.4	100.0%	12[illegible]	[illegible]	0.70m	300.0%
Creosote									
Condalia sp.	(7)	127.3	3.5	36.4	1.6	14.0	10.0	0.53	15.1%
Dalia sp.	(4)	72.7	2.0	3.6	0.2	4.0	3.0	0.23	5.2%
Krameria sp.	(10)	181.8	5.0	36.4	1.7	12.0	8.0	0.26	14.7%
Larrea tridentata	(153)	2,781.8	76.5	1,224.0	58.3	92.0	64.0	0.55	198.8%
Prosopis glandulosa	(24)	436.4	12.0	528.0	25.1	20.0	14.0	0.80	51.1%
Rhus microphylla	(2)	36.4	1.0	274.5	13.1%	1.0	1.0	1.72	15.1%
Total	(200)	3,636.4	100.0%	2,100.9	100.0%	144.0%	100.0%	0.57m	300.0%

* The importance value is the sum of the relative density, relative cover, and relative frequency.

Table 9.2. Vegetational analysis of the five Emlen transects.

Species	Density shrubs/ha	Relative density by species	Cover m^2/ha	Relative cover by species	Frequency (%)	Relative frequency by species	Importance value by species*
Mesquite-shinnery oak							
Artemisia filifolia	4,000	6.8	120	6.6	18.0	20.2	33.6
Prosopis glandulosa	0	0	170	9.3	2.0	2.3	11.6
Quercus havardii	54,000	92.5	1,440	78.7	63.0	70.8	242.0
Yucca campestris	400	0.7	99	5.4	6.0	6.7	12.8
Total	58,400	100.0%	1,829	100.0%	89.0%	100.0%	300.0%
Mesquite-grassland							
Prosopis glandulosa	4,000	6.3	760	69.1	25.0	49.0	124.4
Gutierrezia sarothrae	60,000	93.7	340	30.9	26.0	51.0	175.6
Total	64,000	100.0%	1,100	100.0%	51.0%	100.0%	300.0%
Creosotebush							
Condalia sp.	400	1.4	70	2.9	3.0	1.7	6.0
Krameria sp.	9,800	33.3	240	9.9	37.0	21.5	64.7
Larrea tridentata	5,400	18.4	960	39.7	37.0	21.5	79.6
Gutierrezia sarothrae	13,200	44.9	940	38.8	88.0	51.2	134.9
Prosopis glandulosa	400	1.4	190	7.8	6.0	3.5	12.7
Opuntia sp.	200	0.7	20	0.8	1.0	0.6	2.1
Total	29,400	100.1%	2,420.0	100.0%	172.0%	100.0%	300.0%
Hummock-mesquite #1							
Artemisia filifolia	3,200	5.1	110	6.4	13.0	15.5	27.0
Gutierrezia sarothrae	32,000	51.0	330	19.2	32.0	38.1	108.3
Prosopis glandulosa	2,000	3.2	800	46.5	14.0	16.7	66.4
Quercus havardii	25,000	39.8	380	22.1	22.0	26.2	88.1
Yucca campestris	600	0.1	100	5.8	3.0	3.6	9.5
Total	62,800	100.0%	1,720	100.0	84.0%	100.0%	300.0%
Hummock-mesquite #2							
Artemisia filifolia	8,800	16.5	470	16.4	34.0	31.5	64.4
Prosopis glandulosa	400	0.8	1,100	38.3	20.0	18.5	57.6
Quercus havardii	44,000	82.7	1,300	45.3	54.0	50.0	178.0
Total	53,200	100.0%	2,870	100.0%	108.0%	100%	300.0%

*The importance value is the sum of relative density, relative cover, and relative frequency

Table 5.3. Percent groundcover for avian study areas.

	Bare ground	Litter	Grasses	Forbs	Total
[1]Mesquite-oak (grid)	57.3%	35.5%	5.5%	2.0%	100.8%
[2]Mesquite-oak (transect)	61.6%	33.5%	10.4%	2.0%	107.7%
[1]Mesquite-grassland (grid)	52.0%	17.5%	20.5%	9.0%	99.0%
[2]Mesquite-grassland (transect)	63.9%	22.2%	19.3%	3.1%	108.5%
[1]Creosote (grid)	69.0%	16.0%	2.0%	13.0%	100.0%
[2]Creosote (transect)	70.6%	22.6%	7.1%	3.9%	104.2%
[2]Hummock-mesquite transect #1	78.6%	18.1%	3.2%	1.7%	101.9%
[2]Hummock-mesquite transect #2	66.8%	27.2%	7.4%	5.8%	107.2%

[1]Determined by 200 random points--University of New Mexico. See methods and materials for more detail.

[2]Determined by visual estimates of 100 0.5 meter quadrants--Texas Tech University. See methods and materials for more detail.

Table 9.4. Checklist of bird species seen on or near the Waste Isolation Pilot Plant area of New Mexico.

Ardeidae Herons and Egrets

*Great Blue Heron (Ardea herodias)
*Little Blue Heron (Florida caerulea)
Cattle Egret (Bubulcus ibis)
*Snowy Egret (Egretta thula)
Black-crowned Night Heron (Nycticorax nycticorax)

Anatidae Ducks

Mallard (Anas platyrhynchos)
Green-winged Teal (Anas crecca)
Blue-winged Teal (Anas discors)

Cathartidae Vultures

Turkey Vulture (Cathartes aura)

Accipitridae Hawks and Eagles

Red-tailed Hawk (Buteo jamaicensis)
Swainson's Hawk (Buteo swainsoni)
Ferruginous Hawk (Buteo regalis)
Harris' Hawk (Parabuteo unicinctus)
*Golden Eagle (Aquila chrysaetos)
Marsh Hawk (Circus cyaneus)

Falconidae Falcons

Prairie Falcon (Falco mexicanus)
American Kestrel (Falco sparverius)

Tetraonidae Grouse

*Lesser Prairie Chicken (Tympanuchus pallidicinctus)

Phasianidae Quail

Bobwhite (Colinus virginianus)
Scaled Quail (Callipepla squamata)

Gruidae Cranes

Sandhill Crane (Grus canadensis)

Charadriidae Plovers

*Snowy Plover (Charadrius alexandrinus)
*Killdeer (Charadrius vociferus)

Scolopacidae Sandpipers

*Common Snipe (Capella gallinago)

Table 4.4. (cont.)

Recurvirostridae Avocets, Stilts

*American Avocet (Recurvirostra americana)
*Black-necked Stilt (Himantopus mexicanus)

Phalaropodidae Phalaropes

*Wilson's Phalarope (Steganopus tricolor)

Columbidae Pigeons and Doves

Mourning Dove (Zenaida macroura)

Cuculidae Cuckoos

Yellow-billed Cuckoo (Coccyzus americanus)
Roadrunner (Geococcyx californianus)

Tytonidae Barn Owl

Barn Owl (Tyto alba)

Strigiformes Owls

Great Horned Owl (Bubo virginianus)
Burrowing Owl (Athene cunicularia)

Caprimulgidae Nightjars

Poor-will (Phalaenoptilus nuttallii)
*Common Nighthawk (Chordeiles minor)

Alcedinidae Kingfishers

Belted Kingfisher (Megaceryle alcyon)

Picidae Woodpeckers

Common Flicker (Colaptes auratus)
Ladder-backed Woodpecker (Picoides scalaris)

Tyrannidae Flycatchers

Western Kingbird (Tyrannus verticalis)
Scissor-tailed Flycatcher (Muscivora forficata)
*Ash-throated Flycatcher (Myiarchus cinerascens)
Say's Phoebe (Sayornis saya)
Western Flycatcher (Empidonax difficilis)
Western Wood Pewee (Contopus sordidulus)

Alaudidae Larks

Horned Lark (Eremophila alpestris)

Table 9.4. (cont.)

Corvidae Jays

White-necked Raven (Corvus cryptoleucus)

Troglodytidae Wrens

House Wren (Troglodytes aedon)
Carolina Wren (Thryothorus ludovicianus)
Cactus Wren (Campylorhynchus brunneicapillus)
Rock Wren (Salpinctes obsoletus)

Mimidae Mockingbirds, Thrashers

Mockingbird (Mimus polyglottos)
Brown Thrasher (Toxostoma rufum)
Curve-billed Thrasher (Toxostoma curvirostre)
Crissal Thrasher (Toxostoma dorsale)
Sage Thrasher (Oreoscoptes montanus)

Laniidae Shrikes

Loggerhead Shrike (Lanius ludovicianus)

Sturnidae Starlings

Starling (Sturnus vulgaris)

Parulidae Warblers

Yellow-rumped Warbler (Dendroica coronata)
*Yellow-breasted Chat (Icteria virens)
Wilson's Warbler (Wilsonia pusilla)

Ploceidae Weaver Finches

House Sparrow (Passer domesticus)

Icteridae Blackbirds, Orioles

Eastern Meadowlark (Sturnella magna)
Western Meadowlardk (Sturnella neglecta)
*Yellow-headed Blackbird (Xanthocephalus xanthocephalus)
Red-winged Blackbird (Agelaius phoeniceus)
Northern Oriole (Icterus galbula)
Brewer's Blackbird (Euphagus cyanocephalus)
Brown-headed Cowbird (Molothrus ater)

Fringillidae Grosbeaks, Finches, Sparrows, Buntings

Pyrrhuloxia (Cardinalis sinuata)
*Blue Grosbeak (Guiraca caerulea)
House Finch (Carpodacus mexicanus)
Pine Siskin (Carduelis pinus)
American Goldfinch (Carduelis tristis)

Table 4.4. (cont.)

Fringillidae (cont.)
Green-tailed Towhee (*Pipilo chlorurus*)
Rufous-sided Towhee (*Pipilo erythrophthalmus*)
Lark Bunting (*Calamospiza melanocorys*)
Savannah Sparrow (*Passerculus sandwichensis*)
Vesper Sparrow (*Pooecetes gramineus*)
Lark Sparrow (*Chondestes grammacus*)
Cassin's Sparrow (*Aimophila cassinii*)
Black-throated Sparrow (*Amphispiza bilineata*)
Sage Sparrow (*Amphispiza belli*)
Dark-eyed Junco (*Junco hyemalis*)
Clay-colored Sparrow (*Spizella pallida*)
Brewer's Sparrow (*Spizella breweri*)
White-crowned Sparrow (*Zonotrichia leucophrys*)

[1] Includes stock tanks on area, nearby salt lakes, and Pecos River.

* Indicates species added to the list during summer 1978.

Table 9.5. Estimated densities of avian species per 100 ha in the shinnery oak-mesquite plant type during censuses taken December 1977-March 1978.

Species	29 Dec.	29 Jan.	19 Feb.	24 March
Red-tailed Hawk			<1	
Harris' Hawk	<1	<1	<1	<1
Marsh Hawk		<1	<1	
Sparrow Hawk	<1			<1
Scaled Quail	4	4	4	1
Mourning Dove		<1		
Roadrunner		<1		1
White-necked Raven				<1
Cactus Wren	1	1	1	1
Crissal Thrasher	1	1	1	
Loggerhead Shrike	4	4	3	5
Western Meadowlark			<1	1
Vesper's Sparrow		1		
Black-throated Sparrow		3	1	1
Sage Sparrow	4	2	2	

Table 9.6. Results of monthly roadside census, May-September 1978.

Species	May 21		June 11		July 8		Aug. 12		Sept. 2		Sept. 3	
	Total no.[1]	Stops per species[2]	Total no.	Stops per species	Total no.	Stops per species	Total no.	Stops per species	Total no.	Stops per species	Total no.	Stops per species
Turkey Vulture	2	2	0	0	0	0	4	2	14	10	1	1
Red-tailed Hawk	0	0	1	1	1	1	0	0	0	0	2	2
Swainson's Hawk	0	0	1	1	2	2	3	3	6	6	4	3
Harris' Hawk	2	2	2	2	1	1	2	1	5	5	1	1
Golden Eagle	1	1	0	0	0	0	0	0	0	0	0	0
Marsh Hawk	1	1	0	0	0	0	0	0	0	0	1	1
American Kestrel	0	0	0	0	0	0	0	0	2	2	2	2
Bobwhite	0	0	2	2	0	0	0	0	0	0	0	0
Scaled Quail	5	3	5	4	5	5	2	2	8	7	5	5
Mourning Dove	5	3	4	3	9	5	37	17	95	22	64	13
Roadrunner	1	1	0	0	0	0	1	1	0	0	0	0
Great Horned Owl	0	0	0	0	0	0	1	1	0	0	0	0
Poor-will	0	0	0	0	0	0	0	0	1	1	0	0
Common Nighthawk	18	11	21	14	13	8	9	5	0	0	1	1
Ladder-backed Woodpecker	0	0	3	3	1	1	0	0	2	2	2	2
Western Kingbird	8	5	4	3	7	2	0	0	1	1	0	0
Scissor-tailed Flycatcher	0	0	0	0	2	1	0	0	0	0	0	0
Ash-throated Flycatcher	2	2	6	5	2	2	0	0	0	0	0	0
Say's Phoebe	1	1	0	0	0	0	0	0	0	0	0	0
Western Wood Pewee	1	1	1	1	0	0	0	0	1	1	1	1
Barn Swallow	5	1	0	0	2	1	0	0	0	0	0	0
White-necked Raven	13	11	1	1	9	6	13	5	1	1	0	0
Cactus Wren	17	14	23	19	10	9	11	11	30	24	17	11
Mockingbird	14	11	24	18	23	17	10	6	28	16	9	6
Curve-billed Thrasher	5	4	0	0	2	2	0	0	0	0	0	0

Table 9.6. (cont.).

Species	May 21		June 11		July 8		Aug. 12		Sept. 2		Sept. 3	
	Total no.[1]	Stops per species[2]	Total no.	Stops per species	Total no.	Stops per species	Total no.	Stops per species	Total no.	Stops per species	Total no.	Stops per species
Crissal Thrasher	0	0	1	1	2	1	0	0	1	1	1	1
Loggerhead Shrike	7	7	2	2	4	4	26	17	18	14	36	25
Yellow-rumped Warbler	0	0	1	1	0	0	0	0	0	0	0	0
House Sparrow	5	2	8	1	0	0	0	0	0	0	0	0
Eastern Meadowlark	0	0	4	2	0	0	0	0	0	0	0	0
Western Meadowlark	3	3	2	2	4	4	0	0	0	0	0	0
Meadowlark sp.	0	0	0	0	0	0	0	0	1	1	0	0
Yellow-headed Blackbird	0	0	0	0	0	0	0	0	0	0	2	2
Northern Oriole	3	2	2	2	0	0	0	0	0	0	0	0
Brewer's Blackbird	1	1	0	0	0	0	0	0	0	0	0	0
Brown-headed Cowbird	9	8	4	4	3	3	0	0	0	0	0	0
Pyrrhuloxia	56	34	38	24	38	27	30	18	19	12	18	12
Lark Bunting	18	1	0	0	0	0	0	0	0	0	16	1
Black-throated Sparrow	74	40	39	27	33	22	38	23	9	8	4	4
Cassin's Sparrow	10	6	14	6	15	9	4	2	0	0	0	0
Total species observed	27		25		22		16		17		19	
Total individuals observed	287		213		188		192		171		187	

[1]Total number of individuals seen during the census.

[2]Total number of stops (out of 50) at which the species was seen.

Table 9.7. Densities of individual species by the Emlen transect method in individuals per km^2.

Species	[illegible]	[illegible]	[illegible]	[illegible] #1	[illegible] #2
[illegible] Hawk	[illegible]	[illegible]	--	--	--
[illegible] Quail	[illegible]	[illegible]	[illegible]	4.0	[illegible]
[illegible] Quail	[illegible]	--	--	--	--
[illegible] Dove	[illegible]	--	[illegible]	6.0	1.4
[illegible] Owl	[illegible]	--	--	--	0.7
[illegible] Nighthawk	[illegible]	--	[illegible]	7.4	6.0
[illegible] Red-bellied Woodpecker	--	[illegible]	--	79.4	4.0
[illegible] Kingbird	[illegible]	[illegible]	--	2.0	--
[illegible]-tailed Flycatcher	[illegible]	[illegible]	--	--	--
[illegible] Flycatcher	--	[illegible]	--	5.4	2.6
[illegible] Wood Pewee	--	2.0	--	0.7	--
[illegible] Swallow	--	--	[illegible]	--	--
[illegible] Swallow	--	--	--	0.7	--
[illegible] Red Eye	[illegible]	[illegible]	--	1.4	2.0
[illegible] Wren	[illegible]	[illegible]	1.4	[illegible]	10.1
[illegible] Kingbird	[illegible]	[illegible]	--	[illegible]	48.6
[illegible]-billed Flycatcher	--	--	1.4	--	2.0
[illegible] Thrasher	--	--	0.7	2.0	3.4
[illegible]-headed Shrike	[illegible]	1.4	1.4	1.4	5.4
[illegible] Meadowlark	[illegible]	[illegible]	--	--	--
[illegible] Meadowlark	--	--	21.4	--	--
[illegible] Oriole	[illegible]	0.7	--	0.7	--
Brown-headed Cowbird	0.7	6.0	20.2	5.4	37.[illegible]
Pyrrhuloxia	2.0	4.7	4.0	[illegible]	56.6
Blue Grosbeak	--	10.1	0.7	1.4	--
Black-throated Sparrow	6.8	--	212.3	223.8	112.4
Cassin's Sparrow	--	2.0	71.0	--	--
Total	[illegible]/km^2	[illegible]/km^2	[illegible]/km^2	[illegible]/km^2	[illegible]/km^2
27 species	17 species	17 species	14 species	18 species	15 species

Table 9.8. Breeding bird density and territory size in three different habitat types.

Habitate type	May		July	
	Density individuals per 9 ha	Average territory size, ha	Density individuals per 9 ha	Average territory per 9 ha
Mesquite-shinnery oak				
White-necked Raven	2	*	0	--
Mockingbird	2	1.25	0	--
Loggerhead Shrike	2	*	0	--
Western Meadowlark	2	*	0	--
Black-throated Sparrow	2	0.92	0	--
5 species Total	10			
Mesquite-grassland				
Scaled Quail	2	*	--	--
Mourning Dove	--	--	2	*
Ladder-backed Woodpeckers	2	0.55	2	0.29
Ash-throated Flycatcher	2	*	--	--
Western Wood Pewee	2	0.20	--	--
Scissor-tailed Flycatcher	--	--	2	*
Cactus Wren	2	0.52	4	0.52
Mockingbird	4	0.66	6	0.55
Curve-billed Thrasher	2	*	--	--
Loggerhead Shrike	2	0.33	2	*
Western Meadowlark	2	*	2	*
Northern Oriole	2	0.25	2	0.70
Brown-headed Cowbird	--	--	2	*
Blue Grosbeak	2	0.65	4	0.21
Pyrrhuloxia	2	*	2	*
14 species Total	26		30	
Creosotebush				
Mourning Dove	2	*	2	*
Common Nighthawk	--	--	2	*
Barn Swallow	--	--	2	*
Cliff Swallow	--	--	2	*
Western Meadowlark	--	--	2	*
Cassin's Sparrow	4	0.41	6	0.30
Black-throated Sparrow	10	0.55	10	0.27
7 species Total	16		26	

*Individuals seen on the 9-ha grid but sightings were too few to determine territory size or breeding status.

Table 9.9. Summary of nests found during summer 1978.

Species	Nest material	Nest site (n)	Average height of tree or shrub which holds nest m	Average nest height m
Harris Hawk	Twigs/sticks lined with sticks	Sapindus (1) (Soapberry)	3.66	2.44
Roadrunner	Twigs	abandoned shack (1)	3.05	1.22
	Twigs	Yucca torreyi (1)	2.75	1.83
Burrowing Owl	--	burrow (1)	underground	underground
Poor-will	--	bare ground (1)	on ground	on ground
Common Nighthawk	--	bare ground (1)	on ground	on ground
Scissor-tailed Flycatcher	Forbs/grass	telephone pole (1)	10.68	9.15
	Forbs/grass	Prosopis (2)	2.44	1.62
Ash-throated Flycatcher	Hole in fence post	fence post (1)	2.14	1.83
	Hole in dead mesquite	Prosopis (1)	2.44	1.53
Western Kingbird	Grass/forbs	gas well (1)	4.56	3.66
Ladder-backed Woodpecker	Hole in mesquite	Prosopis (2)	3.81	.82
White-necked Raven	Sticks/twigs	Celtis neticulata (1) (Hackberrgy)	4.58	3.05
		Prosopis (8)	3.63	2.59
		Sapindus (3)	2.53	1.83
		Windmill (1)	9.15	6.10
		gas well (1)	4.58	3.66
Cactus Wren	Grass/forbs/leaves	Prosopis (4)	2.75	1.74
		dead Prosopis (1)	3.05	1.83
		Celtis neticulata (1)	4.58	1.53
		Yucca torreyi (1)	2.44	1.83
		hole in fence post (1)	2.14	1.83
Mockingbird	Twigs/forbs	Prosopis (1)	1.83	.92
		Sapindus (1)	3.05	.92
		Rhus microphylla (1)	2.44	.76
		Yucca torreyi (1)	1.22	.61
Curve-billed Thrasher	Twigs	weather station (1)	3.05	1.83
	Twigs	wooden barn (1)	3.05	2.75
Crissal Thrasher	Twigs	Prosopis (1)	2.44	.92
Pyrrhuloxia	Twigs/forbs/grasses	Prosopis (1)	3.66	1.22
Black-throated Sparrow	Forbs/grasses	Larrea tridentata (1)	.76	.05

Table 9.10. Fates of nests found during summer 1978.

Species	Date nest found	No. eggs/ young in nest when found	No. eggs in full clutch	Eggs hatched		Birds fledged		
				No.	% of full clutch	No.	% of hatching	% of clutch
Harris' Hawk	13 June	0/1	--	-	--	--	--	--
Roadrunner (1)	27 May	0/1	--	1	--	1	--	--
(2)	11 June	5/0	5	5	100	5	100	100
(3)	22 May	6/0	7	7	100	7	100	100
Burrowing Owl	4 June	--	--	--	--	--	--	--
Poor-will	24 July	1/1	2	1	50	1	100	50
Common Nighthawk	14 June	0/2	--	2	--	2	100	--
Scissor-tailed Flycatcher (1)	21 May	--	--	2	--	2	--	--
(2)	29 May	0/0	4	0	0	0	0	0
(3)	11 June	0/0	4	4	100	4	100	100
Ashthroated Flycatcher (1)	16 June	--	--	--	--	3	--	--
(2)	26 June	--	--	--	--	3	--	--
Western Kingbird	6 July	--	--	--	--	4	--	--
Ladder-backed Woodpecker (1)	26 May	--	--	--	--	--	--	--
(2)	27 May	--	--	--	--	-	--	--
White-necked Raven (1)	17 May	6/0	6	3	50	3	100	50
(2)	16 May	5/0	6	2	50	0	0	0
(3)	23 May	3/0	3	0	0	0	0	0
(4)	30 May	3/0	3	0	0	0	0	0
(5)	2 June	0/0	3	3	100	3	100	100
(6)	2 June	4/0	4	--	--	--	--	--
(7)	4 June	4/0	4	3	75	3	100	75
(8)	3 June	1/0	4	0	0	0	0	0
(9)	11 June	0/0	6	5	83	3	60	50
(10)	13 June	5/0	5	0	0	0	0	0
(11)	16 June	5/0	5	0	0	0	0	0
(12)	24 June	--	--	--	--	-	--	--

Table 9.10. (cont.).

Species	Date nest found	No. eggs/ young in nest when found	No. eggs in full clutch[1]	Eggs hatched		Birds fledged		
				No.	% of full clutch[1]	No.	% of eggs hatched	% of full clutch[1]
White-necked raven (13)	4 July	--	--	--	--	[illegible]	--	--
(14)	7 July	4/1	5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Cactus wren (1)	23 May	5/0	5	[illegible]	[illegible]			
(2)	27 May	4/0	4	[illegible]				
(3)	27 May	2/0	--	[illegible]				
(4)	2 June	3/4	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(5)	12 June	1/4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(6)	12 June	2/0	--					[illegible]
(7)	16 June	4/0	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(8)	7 July	--	--	--	--	[illegible]	--	--
(9)	12 August	2/0	--					[illegible]
Mockingbird (1)	31 May	4/0	4	[illegible]		[illegible]	[illegible]	[illegible]
(2)	11 June	5/0	[illegible]	[illegible]				[illegible]
(3)	13 June	4/0	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(4)	6 July	[illegible]/0	4	--	--	--	--	--
Crissal thrasher	1 July	0/0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
Pyrrhuloxia	28 May	0/0	4	4	100	[illegible]	[illegible]	[illegible]
Black-throated sparrow	6 July	4/0	4	--	--	--	--	--

Table 9.11. Growth in nestling Roadrunners.

Age in Days	Nest 1 Hatching Sequence 1	2	3	4	5	Nest 2 Hatching Sequence 1	2	3	4	5	6	7
0				18.3		14.3			14.			
1					25.[illegible]		[illegible]					
2			38.3					24.[illegible]				
3				45.0		4[illegible].5	[illegible]					
4		55.3			34.[illegible]							
5	67.3		70.0			[illegible]						4[illegible].
6				64.3							[illegible]1.	
7		85.0								[illegible].		
8	100.0		96.3						[illegible].			
9					81.3							
10		117.3						[illegible]				
11	126.3			121.3			121.					
12												
13			fledged			151.						
14												
15		fledged										
16	fledged											
17												
18												
19												
33												
34												
35												

Table [illegible].12. Growth in nestling White-necked Ravens.

Age in Days	Nest 1 Hatching Sequence 1	2	3	Nest 2 Hatching Sequence 1	2	3	4	5
0		22.5	22.3					13.3
1	30.5	33.5	24.3			17.3	17.3	
2	43.5	37.8			21.3			
3	49.3			24.4				
4			55.3			41.	38.	
5	83.3			5[illegible]				
6	99.3		94.3	51.3				
7		126.3	128.3					
8	163.3	166.3						
9	211.3							
10								
11						141.3	131.3	
12					210.3			
13				226.3				
14						157.3		
15					261.3			
16				267.3				
17			365.0					
18		375.0						
19	400.0							
33			fledged					
34		fledged						
35	fledged. .							

Table [illegible]. Harvest [illegible]

Year	County	[illegible]	Harvest	[illegible]
1977	Eddy	[illegible]	[illegible]	[illegible]
	Lea	[illegible]	[illegible]	[illegible]
1976	Eddy	[illegible]	[illegible]	[illegible]
	Lea	[illegible]	[illegible]	[illegible]
1975	Eddy	[illegible]	[illegible]	[illegible]
	Lea	[illegible]	[illegible]	[illegible]
1974	Eddy	[illegible]	[illegible]	[illegible]
	Lea	[illegible]	[illegible]	[illegible]
1973	Eddy	[illegible]	[illegible]	[illegible]
	Lea	[illegible]	[illegible]	[illegible]
1972	Eddy	[illegible]	[illegible]	[illegible]
	Lea	[illegible]	[illegible]	[illegible]
1971	Eddy	[illegible]	54,144	[illegible]
	Lea	[illegible]	[illegible]	13.70
1970	Eddy	[illegible]	47,[illegible]	[illegible]
	Lea	[illegible]	29,445	[illegible]
1969	Eddy	2,734	37,176	13.60
	Lea	2,920	[illegible]	[illegible]
1968	Eddy	2,054	40,537	19.70
	Lea	2,49[illegible]	[illegible],904	16.00
1967	Eddy	1,965	29,166	14.70
	Lea	[illegible]	25,511	11.90

[a]Obtained from the New Mexico Department of Game and Fish, Santa Fe.

Table 9.14. Harvest data for Scaled Quail[a].

Year	County	Hunters	Harvest	Average Season Bag
1977	Eddy	4,99[illegible]	79,542	15.92
	Lea	[illegible],247	44,[illegible]98	13.67
1976	Eddy	[illegible]	[illegible]	17.50
	Lea	[illegible],916	44,702	15.33
1975	Eddy	[illegible]	50,[illegible]47	14.82
	Lea	[illegible]	38,521	11.64
1974	Eddy	[illegible]	4,171	[illegible].18
	Lea	[illegible]48	8,409	3.39
1973	Eddy	3,625	71,[illegible]	19.59
	Lea	3,766	[illegible]	19.92
1972	Eddy	[illegible]	42,[illegible]	13.70
	Lea	[illegible]	51,296	14.80
1971	Eddy	2,957	39,407	13.30
	Lea	3,182	35,485	11.20
197[illegible]	Eddy	3,388	43,595	12.90
	Lea	3,8[illegible]0	56,289	14.70
1969	Eddy	3,077	39,911	13.00
	Lea	3,989	65,464	16.40
1968	Eddy	2,349	20,107	8.60
	Lea	3,812	39,516	10.40
1967	Eddy	3,106	44,805	14.40
	Lea	4,145	67,441	16.30

[a]Obtained from the New Mexico Department of Game and Fish, Santa Fe.

Table 9.15. Harvest Data for Lesser Prairie Chickens[a].

Year	County	Hunters	Harvest	Average Harvest per Hunter
1977	Eddy	[illegible]		[illegible]
	Lea	[illegible]	[illegible]	[illegible]
1976	Eddy	[illegible]		[illegible]
	Lea	[illegible]	[illegible]	[illegible]
1975	Eddy	[illegible]	[illegible]	[illegible]
	Lea	[illegible]	[illegible]	[illegible]
1974	Eddy	[illegible]	[illegible]	[illegible]
	Lea	[illegible]	[illegible]	[illegible]
1973	Eddy	[illegible]	[illegible]	[illegible]
	Lea	[illegible]	[illegible]	[illegible]
1972	Eddy	7	7	1.00
	Lea	[illegible]	269	[illegible]
1971	Eddy	7	[illegible]	[illegible]
	Lea	143	131	[illegible]
1970	Eddy	---	---	---
	Lea	---	---	---
1969	Eddy	0	0	0.00
	Lea	392	294	0.80
1968	Eddy	0	0	0.00
	Lea	357	197	0.60
1967	Eddy	0	0	0.00
	Lea	355	173	0.59

[a]Obtained from the New Mexico Department of Game and Fish, Santa Fe.

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CHAPTER 10

A PROGRESS REPORT ON AMPHIBIANS, REPTILES, AND MAMMALS AT THE LOS MEDAÑOS WASTE ISOLATION PILOT PLANT (WIPP) PROJECT AREA OF NEW MEXICO

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Introduction

The 1978 field work consisted primarily of studies of amphibians, reptiles, and mammals within a 5-mi radius around ERDA 9 (Fig. 10.1). During 1975, 1976, and 1977, studies were conducted within a 72 mi^2 study area.[1,2] Because the 5-mi radius study site and 72-mi^2 study site basically encompass the same geographic area, only the 5-mi radius area will be referred to in this report.

In 1978, habitat preferences of amphibians, reptiles, and mammals were examined from five habitat types which included shinnery oak-mesquite, mesquite-grassland, mesquite-snakeweed, creosotebush-grassland, and active duneland. These habitat types relate to the general biological regions stated in Chapter 1 in the following manner: Shinnery oak-mesquite corresponds to the "oak-mesquite area," mesquite-grassland to the "mesa," and creosotebush-grassland to the "creosotebush area." Mesquite-snakeweed is included in the "oak-mesquite area." Active duneland includes the "dune" and "hummock-mesquite" areas described in Chapter 1. Studies of reptiles included weekly captures of side-blotched lizards and western whiptail lizards for stomach analysis, determination of lizard densities on a 1-ha study grid, and plant composition studies on that grid. Studies involving mammals during 1978 consisted of the following: (1) sample collections of Ord's kangaroo rats and spotted ground squirrels

from 1/4-section areas each month and determination of vegetative compositions from those 1/4 sections; (2) monthly samples of desert cottontails; (3) densities of small rodents on a 90 x 90 m grid and vegetative composition on that grid; (4) densities, immigration, and emigration of Ord's kangaroo rats on a 275 x 275-m (7.56-ha) grid and vegetative composition on that grid; and (5) densities of lagomorphs.

Methods

Amphibians and Reptiles

Amphibians and reptiles from various habitats were observed, collected by hand, or killed with dust shot during the period from January 14 to September 30, 1978. Representatives of each species from the five habitats were prepared for deposition in the Eastern New Mexico University (ENMU) Natural History Museum.

An attempt was made to capture five side-blotched lizards and five western whiptailed lizards each week from May 15 through August 15, 1978. All specimens were labeled and preserved in alcohol and stored for future analysis of stomach contents.

Lizard densities were estimated by counting lizards directly with a cruise method.[3] The study area was 1 ha in size and was marked off into 10 x 10 m units. Lizards were counted by walking the plot as shown in Gennaro and Jorgensen.[1] Counts began in May 1978 and were conducted periodically through August 15 when the temperature of sun-exposed soils on the study plot reached 34°C. Soil temperatures were taken by placing the temperature probe on the soil surface. Probes were shaded during the sun readings.

Frequency values of plants on the study grids were obtained during each study period by using a point-sampling technique, with the points spaced at 2-m intervals along transects run within the grid. Frequency values were based upon an analysis of 200 points and involved the

recording of all plant species which occurred at the tip of the boot at each point; that method of analysis places tall and short plants on a par. The normal spread of the plant beyond its ground level was used in the determination of those individuals which occurred at each point and included the farthest spread of stems and leaves. Transect points which did not come in contact with plant species were recorded as either exposed surface soil areas or litter covered points. Plant nomenclature mostly followed Correll and Johnston[4] and Gould.[5]

Mammals

Sight observations of terrestrial mammals and a search for tracks continued from January 15, 1975 to September 30, 1978. All prepared skins were deposited within the ENMU Natural History Museum.

Beginning in March 1978, an attempt was made during each subsequent new moon phase to kill-trap 50 Ord's kangaroo rats and 10 spotted ground squirrels from 1/4-section areas (referred to as small mammal removal sites) generally in shinnery oak-mesquite habitat. A different 1/4 section was selected for each trapping session. During those same periods, an attempt was made to collect 10 desert cottontails with shotgun from shinnery oak-mesquite. Ectoparasites, endoparasites, skins, skulls, bacula, digestive organs, food materials, and reproductive parts from those mammals were preserved for future studies.

Lagomorph densities were determined from a 60 x 16,667 m strip (1 km^2 or 100 ha) in shinnery oak-mesquite by traveling a dirt road (which was 30 m from each margin of the strip throughout its length). The 100-ha strip was surveyed 17 times. One driver and one observer counted the lagomorphs from a vehicle traveling 15 mph. Each census began 1 h before sunset.

Sherman live traps (7.5 x 7.5 x 22.5 cm) baited with rolled milo were used to sample small mammals on two grids. One grid was 90 x 90 m and the other was 275 x 275 m (Fig. 10.2).[6]

On the 90 x 90-m grid, two traps were placed at each of 100 stations. The stations were 10 m apart. Traps were kept open for two prebait periods and then supplied with bait for two bait periods. During the 1978 spring census, prebait periods were March 12-14 and 20-22; bait periods were March 14-19 and 23-27. During the 1978 summer census, prebait periods were June 3-5 and 11-13; bait periods were June 6-10 and 14-18. Traps were checked in the morning and evening during the trapping periods. Each captured mammal was ear-tagged or toe-clipped, weighed to the nearest 0.1 g on a Dial-O-Gram scale, and examined for sex and reproductive condition. Mammalian densities were determined using Hayne's method.[7] Plants were surveyed on the 90 x 90-m grid in the same manner as they were surveyed on the 1-ha lizard grid.

Two Sherman traps were placed at each of 144 stations of the larger grid (Fig. 10.2). The stations were 25 m apart. That distance is the recapture radius for Ord's kangaroo rat.[1] The perimeter line was positioned 25 m from the outer edge of the grid. Traps were not placed on that line. The X line (the innermost of three lines forming the dense line) was positioned 25 m from the perimeter line. Traps were placed 25 m apart on the X line. The Y line was positioned 25 m from the X, and traps were placed 25 m apart on that line. The last line of the dense line, the Z line, was placed 10 m from the Y line. Traps were positioned 8.3 m apart on the Z line. The total sampling area was 445 x 445 m (19.8 ha) in size, and consisted of the inner grid, perimeter line, and dense lines.

A census on the 7.56-ha grid began on the evening of July 19, 1978. Traps were checked for animals at sunrise each morning, closed, and rebaited with rolled milo each evening from July 20 through and including July 29, a period of 10 days. Each captured animal was ear-tagged and sexed. Mammalian densities were determined using Hayne's method.[7]

Four 5-m transects were run from each one of the 144 stakes comprising the inner grid to determine percentage coverage of plants and percentage coverage of bare ground. Two of the transects were run north-south, one on each side of the stake; and two were run east-west, one on each side of the stake.

Pearson's product-moment correlation coefficients were calculated between characters of each data set for each group of organisms on the 7.56-ha grid to determine correlations between variables.[8] Sokal and Rohlf[9] present an explanation of those techniques.[8] Three-dimensional displays of plant genera and small mammals from the 7.56-ha grid were plotted using RSCORS[9] on a Stromberg-Carlson 4020 plotter. The plotter was incorporated on a CDC 7600 computer at Sandia Laboratories in Albuquerque, New Mexico.

Results and Discussion

Various sources of published information include species of amphibians, reptiles, and mammals on or near the study area that were not recorded during the study.[10-18] Those species are listed in Table 10.1.

Amphibians and Reptiles

A checklist of amphibians and reptiles from the study area is presented in Table 10.2. Also included are habitats, abundance status, and observation records of the species captured. The record includes an observation period from August 29, 1975 to September 30, 1978, with data from Gennaro and Jorgensen.[1,2] (See Gennaro (1978) Appendix 10.1 for list of voucher specimens.[19])

A total of 45 side-blotched lizards and 62 western whiptail lizards were collected for future stomach analyses. Gennaro's (1978) Appendix 10.2 contains a list of those specimens, and Appendix 10.3 lists specimens captured for stomach analysis in 1976 and 1977.[19] All specimens were stored at the ENMU Natural History Museum.

Estimates of the densities of three species of lizards are shown in Table 10.3. The side-blotched lizard was the most abundant species during all months of the survey. The numbers of that lizard were higher in April than any other month. The western whiptail and six-lined racerunner were

not observed on the grid until May. Both species were similar in abundance during all months except May; then, there were twice as many whiptails as racerunners. Lizard species observed during previous years[1,2] and not during 1978 included the leopard lizard, lesser earless lizard, and Texas horned lizard.

Density records of lizards in shinnery oak-mesquite during 1976, 1977, and 1978 (Table 10.4) indicated that the number of side-blotched lizards was about the same in 1977 and 1978. Counts during 1977 and 1978 were half (June 1977), or less than half of those present in 1976. The numbers of western whiptails were about the same over the 3-year period. The numbers of racerunners were higher in 1978 than the previous two years.

Mammals

A checklist of mammals from the study area is presented in Table 10.2. Data listed include habitat, abundance status, and observation records of the species captured. The record includes an observation period from August 29, 1975 to September 30, 1978, with data from Gennaro and Jorgensen.[1,2] Gennaro's (1978) Appendix 10.1 contains a list of voucher specimens.[19]

Numbers of Ord's kangaroo rats, spotted ground squirrels, and desert cottontails captured for future studies are shown in Tables 10.5, 10.6, and 10.7, respectively (Gennaro (1978), Appendix 10.4).[19] Appendix 10.5[19] contains a list of other vertebrates captured within the 5-mi radius area around ERDA 9, but not used for analyses of internal body parts or stomach contents. The goal of 50 Ord's kangaroo rats, 10 spotted ground squirrels and 10 desert cotton-tails per collecting period was not attained during all months because of the low trap success for kangaroo rats and ground squirrels and reduced sightings of cottontails per number of man-hours available for hunting.

Ord's kangaroo rat had the highest density of the mammals marked during the spring and summer seasons on the 90 x 90-m grid (Table 10.8).

Although Ord's kangaroo rat had the highest biomass during the spring, the spotted ground squirrel had the highest biomass of the animals marked during the summer. During the spring, species with the highest to the lowest density were Ord's kangaroo rat, northern grasshopper mouse, spotted ground squirrel, and plains pocket mouse. During the summer, species from the highest to the lowest densities were Ord's kangaroo rat, spotted ground squirrel, plains pocket mouse, northern grasshopper mouse, and southern plains woodrat. During the spring, species from the highest to the lowest biomass were Ord's kangaroo rat, northern grass-hopper mouse, spotted ground squirrel, and plains pocket mouse. During the summer, species from the highest to the lowest biomass were spotted ground squirrel, Ord's kangaroo rat, plains pocket mouse, northern grasshopper mouse, and southern plains woodrat.

Reproductive activity was similar for the spring and summer for Ord's kangaroo rat and the northern grasshopper mouse. The spotted ground squirrel had a higher reproductive activity during the summer than during the spring (Table 10.8).

Densities, biomasses, and average movements of mammals on the 90 x 90 m grid for a 3-yr period are shown in Table 10.9. Ord's kangaroo rats had the highest density over the 3-yr period. The spotted ground squirrel showed an increase in density and biomass, and for the first time in 3-yr, had the highest biomass on the grid during the 1978 summer. Densities and biomasses of the other mammals generally showed a decrease over the 3-yr period. Another trend among all species was an increase in average movements as the density decreased.

During the March and June 1977 live trapping periods on the 90 x 90 m grid, Ord's kangaroo rat showed the highest recapture success and lowest mean movements of all the small mammals marked.[2] We concluded that Ord's kangaroo rat appeared to be the most stable mammal on the grid and probably displayed the least amount of immigration and emigration. Those same conclusions apply to the March 1978 trapping period since Ord's kangaroo rat again showed the largest recapture success (Table 10.10) and the lowest average movements (Table 10.11). Spotted ground squirrels and

plains pocket mice had a 100% trap success during that period, but only one specimen of each species was marked. The northern grasshopper mouse also had a high recapture success during the March 1978 period, but the total number of marked grasshopper mice was less than half the number of Ord's kangaroo rats marked.

During the June 1978 period, average movements were about the same for the spotted ground squirrel and Ord's kangaroo rat (Table 10.11). Considering both the first and second trapping periods together during June, both species had about the same recapture success (Table 10.10); thus, both species appeared to display the same amount of stability on the grid during June.

Correlation coefficients between mammalian species and plant genera (also including bare ground) on the 7.56-ha grid are shown in Table 10.12. Correlations were considered meaningful only when more than one specimen of a plant genus was encountered during the survey.

With one exception, there was at least one significant correlation between each species of mammal and plant genera and/or bare ground--male kangaroo rats were not significantly correlated with any plant genus or bare ground. Female Ord's kangaroo rats were positively correlated with Calylophus, Senecio, and Penstemon, and negatively correlated with Artemisia, Yucca, and Pectis. Male northern grasshopper mice were positively correlated with Leptoloma, Dithyrea, and Caesalpinia. Female northern grasshopper mice were positively correlated with Prosopis, Dalea, and Dithyrea. Because the spotted ground squirrel and southern plains woodrat were encountered only a few times on the grid in association with plant genera and bare ground, sexes were combined for each of the species. Spotted ground squirrels were positively correlated with Quercus; southern plains woodrats were positively correlated with bare ground.

A summary of the trapping success for small mammals on the 7.56-ha grid is shown in Table 10.13. Densities for those mammals are in Table 10.14. Densities of the northern grasshopper mouse and southern plains woodrat were less than 1/ha. Ord's had the highest density (1.4/ha).

These density estimates may be lower than the actual densities because of the time of the month the animals were trapped. Trappings began on the night of the full moon to avoid abundant captures. Should a large number of specimens have been captured, several may have died from overexposure to heat before being released. The trapping time is not critical as long as subsequent seasonal surveys are conducted during the same moon phase. The higher densities of small mammals on the 90 x 90-m grid could have resulted from trapping periods being conducted on nights darker than the nights when the 7.56-ha grid was surveyed.

Mammals showed no evidence of emigration or immigration on the 7.56-ha grid. The following criteria were used to reach that conclusion: Emigration would have occurred if an animal were captured 3 or more successive times on the inner grid (275 x 275 m) and then captured on the X, Y, and Z line. Immigration would have occurred if an animal were captured on the inner grid following its capture on the X, Y, or Z line.

Movements of small mammals on the 7.56-ha grid are shown in Table 10.15. Standard deviations indicate overlap among the movements of all the mammals, the least being shown by male northern grasshopper mice. The diet of that species is largely carnivorous,[20] and thus may require that a larger area be covered per-unit-time than for the herbivorous species.

Home range sizes of small mammals on the 7.56-ha grid are shown in Table 10.16. Again, the diet of the grasshopper mouse may cause its home range to be larger than that of the herbivorous Ord's kangaroo rat. No overlap in home range size between those two species occurred, i.e., $\pm$ 1 standard deviation.

The three-dimensional distributions of plant genera, bare ground, and small mammals on the 7.56-ha grid are shown in Figures 10.4 to 10.51. On each drawing, the left side of the base is the western edge of the grid. Plants and bare ground are in percentages; mammals are in numbers. A flat base on the figure indicates zero percentages or numbers. The highest

point on a figure represents the highest percentage or number of a variable. The height of other points on that same figure is proportionally related to the highest point. The highest value varies considerably among the plant genera and mammalian species studied.

The census results for blacktail jackrabbits and desert cottontails are shown in Figure 10.3. The lowest number of jackrabbits was observed in March ($4.3/km^2$). The lowest number of cottontails was observed in June ($0.67/km^2$). The highest number of jackrabbits was in August ($25.5/km^2$). Cottontail counts were highest in April ($5/km^2$) and August ($5/km^2$).

During 1977 and 1978, the lagomorph counts per month were always higher for jackrabbits than cottontails (Table 10.17). Jackrabbits were generally higher in number during April, June, July, and August of 1978 than the same months of the 1977 summer. The opposite trend was noted among cottontails. During May, June, and July, cottontail counts were higher in 1977 than 1978; however, more cottontails were counted during August 1978 than August 1977.

The New Mexico Department of Game and Fish has obtained deer harvest data from eastern Eddy and southern Lea counties. The 5-mi radius area around ERDA 9 is within their survey site. The results of those surveys showing deer harvest, unit hunter pressure, percentage of hunter success, and hunter days/deer harvest are shown in Table 10.18.

Indices for relative predator abundance from two areas in southeastern New Mexico were obtained from Fish and Wildlife Service reports (1972-1977).[21-26] Those data are shown in Table 10.19. The data were obtained by recording tracks from scent stations along two survey routes, each 14.7 mi in length. One route (survey route 23) began 12 mi east of Carlsbad and continued eastward for 14.7 mi. The last 5 mi of that route were within the 5-mi radius area around ERDA 9. The other route (survey route 24) began 30 mi southeast of Carlsbad and continued eastward for 14.7 mi. That route was about 12 mi south of the boundary of the five-mile radius area.

Plants

General considerations -- Certain factors could be influential in causing data fluctuations:

1. The degree of preciseness of the method used is such that differences in species frequencies occur which are directly attributable to the methodology itself. This could be especially applicable to the 1-ha lizard study site and the 90 x 90 m live mammal grid, in which the same area was repeatedly studied during the spring and summer months.

2. The phenology of individual plant species could result in increases or decreases in frequency values, depending upon the season (or month) of analysis.

3. The very local nature of the summer rainfall in the area, combined with a general increase in soil drying as the summer progressed, could be reflected in corresponding fluctuations in plant frequencies during the late summer months.

4. Monthly variations in the data could be a reflection of habitat differences, many of which are undoubtedly of a very subtle nature. This factor could be of some importance in evaluating data fluctuations obtained from the small mammal removal sites, since this study involved an analysis of six different areas.

Some of the above factors will be covered in more detail later in this report.

Data Analysis and Presentation -- Frequency data for individual species are represented in Tables 10.20-10.22 and are designated on the basis of type of animal study site and dates of analyses. The tables also contain frequency values for the noncontact points which have been designated as either exposed soil surface points or litter covered areas. In addition, the quantitative relationship between contact and noncontact points at each study site (and date of analysis) is presented in Table 10.23 in the form of a TF/NCP ratio. The TF value represents the total plant frequencies (expressed in a percentage value)/sample date. Total frequency (TF) is obtained through a summation of individual species frequencies for each sample site and sample date. Noncontact point (NCP) values represent the total NCP (as percentage)/sample date and include both bare ground and litter covered points. Low TF/NCP ratios are

indicative of a relatively sparse plant cover; conversely, high values suggest sites with greater plant cover, or possibly areas where plant layering is more prominent.

Lizard grid (1 ha) -- Dominant species on the lizard grid were *Aristida purpurea* and *Quercus havardii*, both of which exhibited frequency values of 10% or higher for all three sample dates (Table 10.20). Species which yielded fairly high frequencies on at least one of the sample dates included *Artemisia filifolia* (7.0%), *Croton dioicus* (11.0%), and *Sporobolus flexuosus* (6.5%).

Some evidence indicated an increase in plant activity as the season progressed. Those changes were apparent in the following areas:

1. Highest TF/NCP ratios were obtained for the later (July and August) sample dates (Table 10.23).

2. Number of species encountered increased from 11 (on May 31) to 15 (for both July 26 and August 13). Those increases, in part, probably reflect the appearance and subsequent growth of the annual species *Munroa squarrosa*, *Panicum capillare*, and *P. arizonicum*.

3. The percentage of nontact points was high for all sample dates (mean, 47.8%, range, 42.5-52.0%), but the number of litter-covered points showed a marked decrease on the August 13 sample date (Table 10.20). That observation might be indicative of continued plant activity during the later months of the growing season.

Mammal grid (90 x 90 m) -- *Quercus havardii* was the most abundant species on this site, with frequency values of 16.5 and 19.0% for the two sample periods (Table 10.21). Other species which exhibited fairly high frequencies included *Aristida purpurea* (9.5 and 7.0%) and *Artemisia filifolia* (6.0 and 5.0%). Species with rather high frequencies for only one of the two sampling dates included *Hedyotis humifusa* (8.0 and 2.0%) and *Panicum* sp. (3.5 and 13.5%). The increase in frequency for *Panicum* can be attributed to the fact that many members of this genus are annual species which develop later in the growing season.

Overall, the data indicated little change in species composition and frequency as the season progressed. The species with the highest frequencies (Q. havardii and A. purpurea) showed only minor variations in those values from one sample date to the next. The same number of species (14) was encountered during both sampling periods, although there were slight differences in species composition when the two sets of data were compared; those differences, however, occurred in low-frequency species and might not reflect true changes in species composition with time (Table 10.21).

The number of noncontact points also showed only minor variation from one sample period to the next (Table 10.23). Such minor variation may result from a lack of floristic changes referred to above, or that both sample dates occurred rather early in the growing season before growth of perennial species and appearance of certain annuals could become apparent.

Small Mammal Removal Sites (1/4-Section Sites) -- Q. havardii was the only species which exhibited a consistently high frequency of occurrence on all sites (Table 10.22). Other species which occurred on each of the six sites and which showed fairly high frequency values for one, or more, of those sites are as follows:

Aristida purpurea	(mean: 5.5%, range: 1.0-9.5%)
Artemisia filifolia	(mean: 4.8%, range: 1.0-7.5%)
Prosopis glandulosa	(mean: 6.4%, range: 0.5-11.5%)
Yucca campestris	(mean: 3.3%, range: 0.5-11.0%)

Species which occasionally exhibited high frequency values, but which were not encountered on every site, included H. humifusa (9%), S. flexuosus (10.0%), and Xanthocephalum sarothrae (8.0%).

All small mammal removal study sites appeared to belong to the same community type; therefore, the data reflect increases in plant activity within this habitat type as the season progressed. These qualitative and quantitative changes occurred in the following areas:

1. *Higher TF/NCP ratios were obtained at the sites sampled on July 2* and August 11 (Table 10.23).

2. The number of species encountered on the transects increased from 10 to 13 in the March through May period to 15 to 18 during the June through August sampling.

3. In conjunction with the above factor, the number of annual species increased from 2 to 5 in the March through May period to 6 to 8 in the June through August samples. Investigators working in other habitat types[27] have also noted an increase in the botanical composition of annual species as the growing season progressed.

The number of noncontact points was quite high at all study sites (mean, 46.8%; range, 34.5 to 68.5%), which means that extensive segments of sandy soils support little, if any, plant cover.

Later analysis periods (July and August) indicated the presence of fewer litter-covered areas (Table 10.22). Excluding the possible effect of field interpretation of this category of points, reduction of the litter-covered areas might be attributable to one or more of the following factors:

1. Increase in the intensity of wind action as summer surface temperatures approach maximum values.

2. Growth in the vicinity of hummocks, which support an appreciable plant cover. As the season progressed, hummocks would expand and occupy more space, decreasing the number of litter-covered areas.

3. Increase in animal foraging activities during the summer.

Summary

Surveys involved a general census of amphibian, reptilian, and mammalian species, and the determination of densities, biomasses, home ranges, and movement of those vertebrates. A total of 27 kinds of amphibians and reptiles and 31 kinds of mammals were collected or observed within the

WIPP area. Those collected were preserved as voucher specimens and deposited in the Natural History Museum at Eastern New Mexico University.

Side-blotched lizards (Uta stansburiana) were more common than any other lizards during 1978, but their numbers have tended to decrease during 1976, 1977, and 1978. Numbers of western whiptails (Cnemidophorus tigris) were about the same over those years, but six-lined racerunners (Cnemidophorus sexlineatus) have increased in number during the same period.

Samples of Ord's kangaroo rats (Dipodomys ordii), spotted ground squirrels (Spermophilus spilosoma), and desert cottontails (Sylvilagus auduboni) were kill-trapped each month from March through September 1978. Their ectoparasites, endoparasites, skins, skulls, bacula, digestive organs, food materials, and reproductive parts were preserved for future studies.

Ord's kangaroo rats had the highest densities on the 90 x 90 m and 275 x 275-m grids. They also had the highest biomass during the spring on the 90 x 90-m grid, but biomass appeared to be higher in spotted ground squirrels during the summer. Generally, all small mammals showed trends toward decreasing densities over a 3-year period on the 90 x 90 m grid--except spotted ground squirrels. They tended to increase in number.

The high recapture success and low movement between captures of Ord's kangaroo rats indicated that they were the most stable mammalian species on the 90 x 90-m grid, thus possibly displaying the least amount of immigration and emigration. That assumption was tentatively verified on a 275 x 275-m grid where evidence of immigration and emigration of Ord's kangaroo rats was not apparent.

Northern grasshopper mice had larger home ranges and greater average movements between captures than other small mammals on the 275 x 275-m grid. The diet of that species is largely carnivorous and may thus require that a larger area be covered per-unit-time compared to herbivorous species on the grid.

With one exception, some significant correlations occurred between all species of mammals and plant genera and/or bare ground on the 7.56-ha grid. Female Ord's rats were positively correlated with Calylophus, Senecio, and Penstemon, and negatively correlated with Artemisia, Yucca, and Pectis. Male northern grasshopper mice were positively correlated with Leptoloma, Dithyrea, and Caesalpini. Female northern grasshopper mice were positively correlated with Prosopis, Dalea, and Dithyrea. Spotted ground squirrels were positively correlated with Quercus; southern plains woodrats were positively correlated with bare ground.

Deer harvest data obtained from the New Mexico Department of Game and Fish indicated that the highest harvest of deer over an 11-year period (1967-1977) was from 1971 through 1974. Relative predator abundance indices obtained from the Denver Wildlife Research Center indicated that coyotes were the most abundant predator on or near the 5-mile radius area around ERDA 9 from 1972 through 1978. Other predators occurring there in order of decreasing abundance were badgers, skunks, gray foxes, and raccoons.

Frequency values of plants on the study grids and 1/4-section removal sites were obtained during 1978 by using a point-sampling technique, with the points spaced at 2-m intervals along transects run within each study site. Those data will be collected each year and studied in relationship to densities and food habits of the mammals.

Acknowledgments

Students assigned to the project and associated with the Natural History Museum at Eastern New Mexico University contributed considerable effort and dedication to this study. They include Fred Bennett, Sandy Campos, Craig Deihl, Douglas Hirt, Ron McClendon, Paul Polechla, and Thomas Soapes. Bill Dahl, Russell Pettit, and their students from Texas Tech University conducted the plant survey on the 7.56-ha grid. Jack Secor conducted most of the other plant surveys, and he assisted in preparation of the plant section of this report. Barbara Best served as the statistical consultant. Diane Holdridge, Division 4514, Sandia Laboratories prepared the three-dimensional displays of plant genera and small mammals from the 7.56-ha grid.

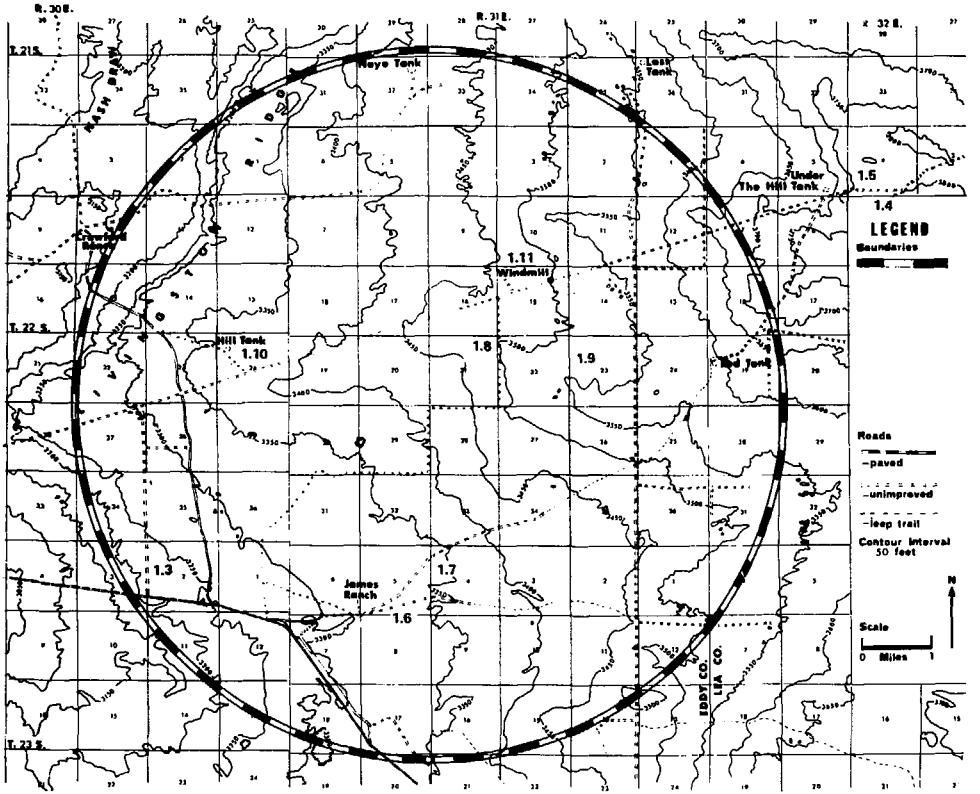

Fig. 10.1. The Los Medaños WIPP Study area 40 km east of Carlsbad, Eddy Co., NM. The large numbers on the map refer to the localities where photos for Figs. 1.3-1.11 were taken.

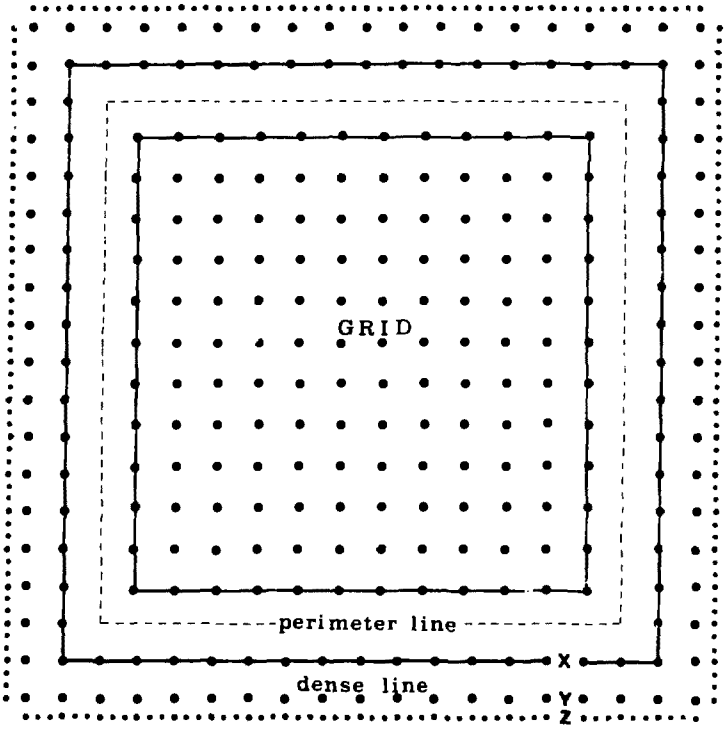

Fig. 10.2. Schematic diagram of the mammal grid and dense line design. The dense line is made up of three (3) lines--X, Y, and Z from the innermost to the outermost. The perimeter line is imaginary and contains no traps.

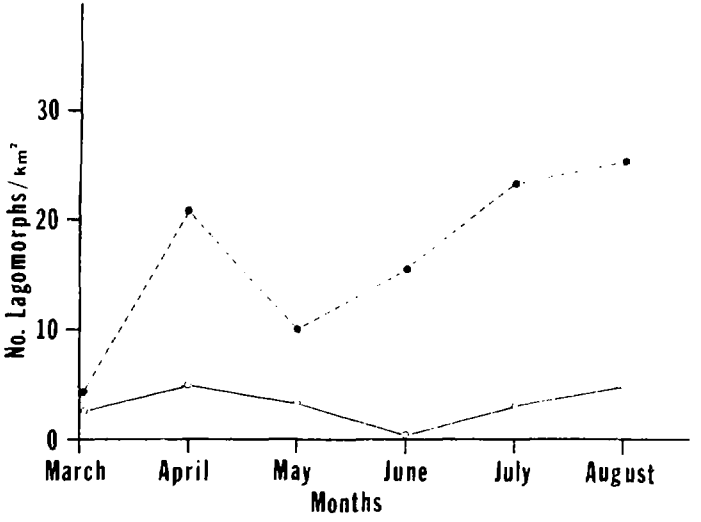

Fig. 10.3. Average numbers of blacktail jackrabbits (dashed line) and desert cottontails (solid line) counted per month during 1978.

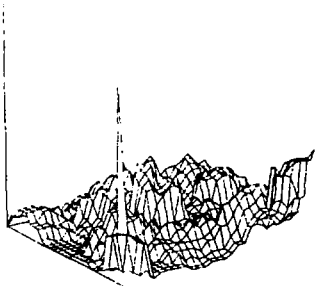

Fig. 10.4. Three-dimensional display showing the distribution of Leptoloma on a 7.56 ha grid.

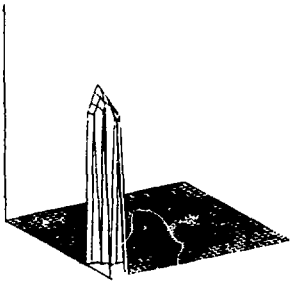

Fig. 10.5. Three-dimensional display showing the distribution of Brachiaria on a 7.56 ha grid.

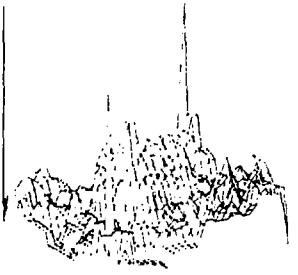

Fig. 10.6. Three-dimensional display showing the distribution of Paspalum on a 7.56 ha grid.

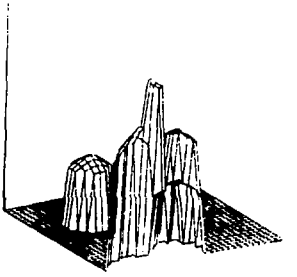

Fig. 10.7. Three-dimensional display showing the distribution of Setaria on a 7.56 ha grid.

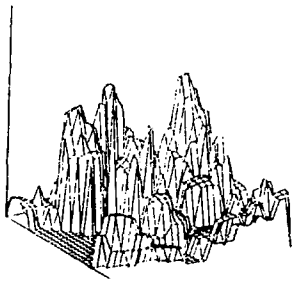

Fig. 10.8. Three-dimensional display showing the distribution of Cenchrus on a 7.56 ha grid.

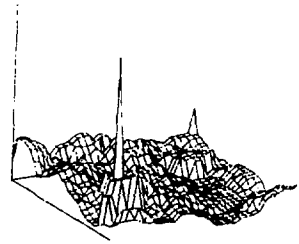

Fig. 10.9. Three-dimensional display showing the distribution of Erioneuron on a 7.56 ha grid.

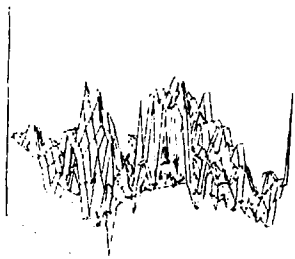

Fig. 10.10. Three-dimensional display showing the distribution of Sporobolus on a 7.56 ha grid.

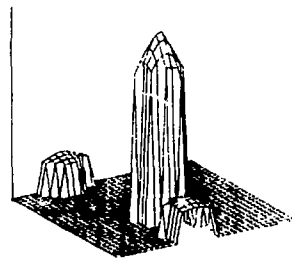

Fig. 10.11. Three-dimensional display showing the distribution of Muhlenbergia on a 7.56 ha grid.

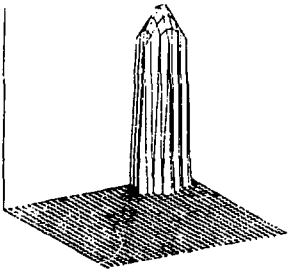

Fig. 10.12. Three-dimensional display showing the distribution of Bouteloua on a 7.56 ha grid.

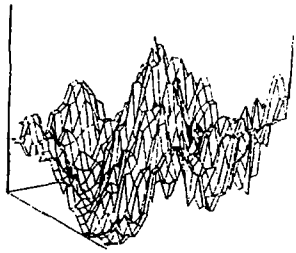

Fig. 10.13. Three-dimensional display showing the distribution of Aristida on a 7.56 ha grid.

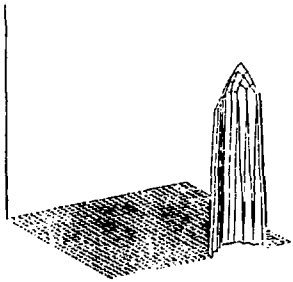

Fig. 10.14. Three-dimensional display showing the distribution of Cyperus on a 7.56 ha grid.

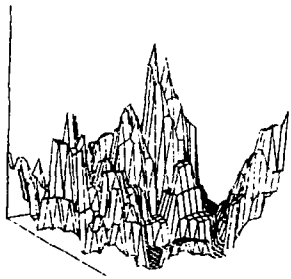

Fig. 10.15. Three-dimensional display showing the distribution of Yucca on a 7.56 ha grid.

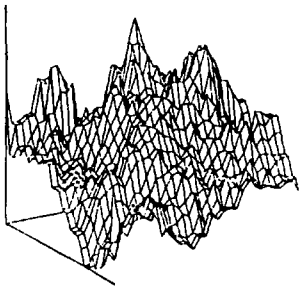

Fig. 10.16. Three-dimensional display showing the distribution of Quercus on a 7.56 ha grid.

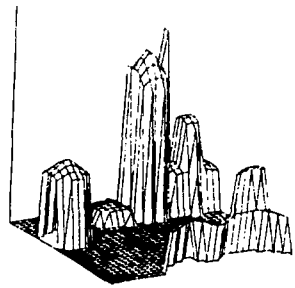

Fig. 10.17. Three-dimensional display showing the distribution of Eriogonum on a 7.56 ha grid.

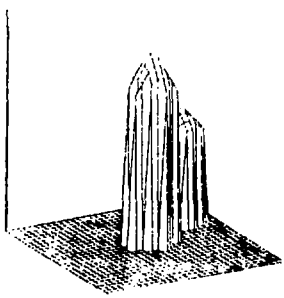

Fig. 10.18. Three-dimensional display showing the distribution of Mirabilis on a 7.56 ha grid.

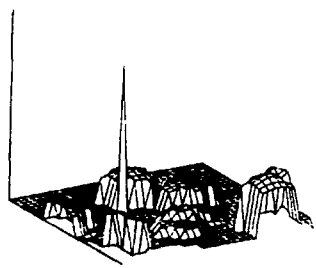

Fig. 10.19. Three-dimensional display showing the distribution of Dithyrea on a 7.56 ha grid.

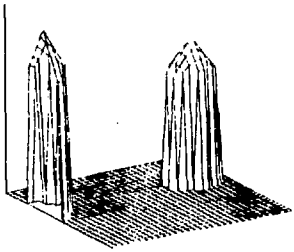

Fig. 10.20. Three-dimensional display showing the distribution of Mimosa on a 7.56 ha grid.

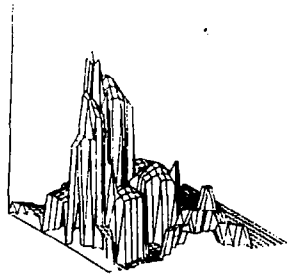

Fig. 10.21. Three-dimensional display showing the distribution of Prosopis on a 7.56 ha grid.

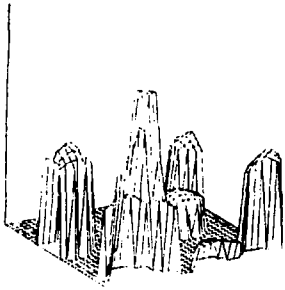

Fig. 10.22. Three-dimensional display showing the distribution of Caesalpinia on a 7.56 ha grid.

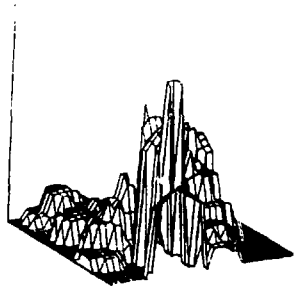

Fig. 10.23. Three-dimensional display showing the distribution of Dalea on a 7.56 ha grid.

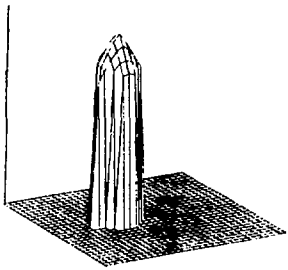

Fig. 10.24. Three-dimensional display showing the distribution of Phyllanthus on a 7.56 ha grid.

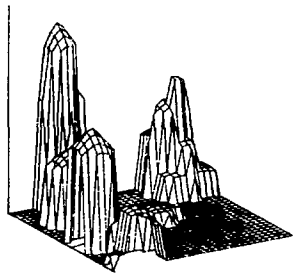

Fig. 10.25. Three-dimensional display showing the distribution of Croton on a 7.56 ha grid.

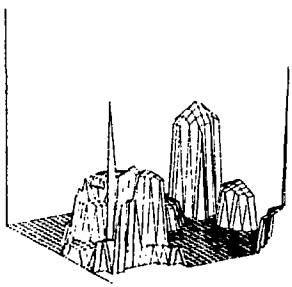

Fig. 10.26. Three-dimensional display showing the distribution of Euphorbia on a 7.56 ha grid.

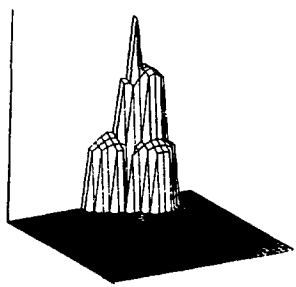

Fig. 10.27. Three-dimensional display showing the distribution of Mentzelia on a 7.56 ha grid.

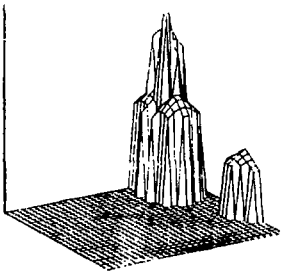

Fig. 10.28. Three-dimensional display showing the distribution of Calylophus on a 7.56 ha grid.

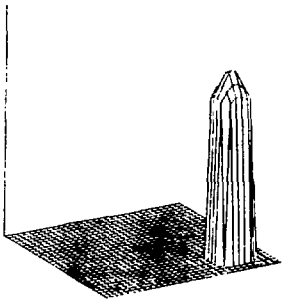

Fig. 10.29. Three-dimensional display showing the distribution of Gaura on a 7.56 ha grid.

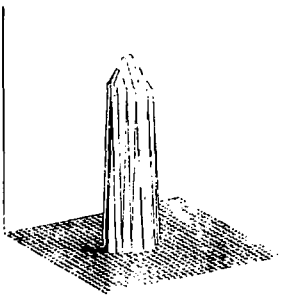

Fig. 10.30. Three-dimensional display showing the distribution of Phacelia on a 7.56 ha grid.

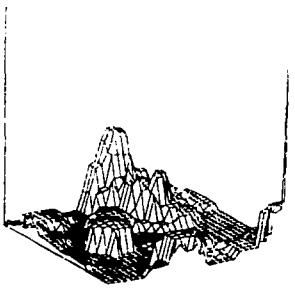

Fig. 10.31. Three-dimensional display showing the distribution of Heliotropium on a 7.56 ha grid.

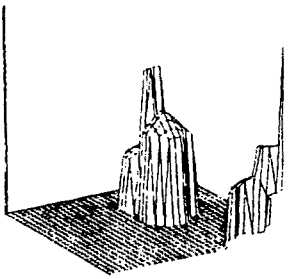

Fig. 10.32. Three-dimensional display showing the distribution of Monarda on a 7.56 ha grid.

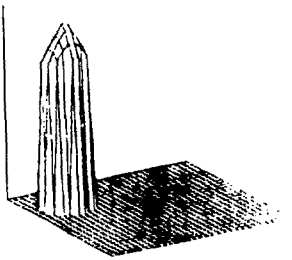

Fig. 10.33. Three-dimensional display showing the distribution of Solanum on a 7.56 ha grid.

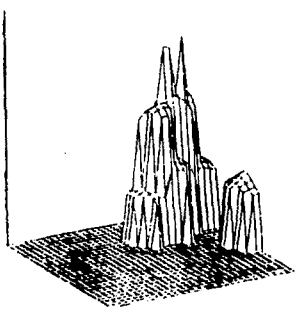

Fig. 10.34. Three-dimensional display showing the distribution of Penstemon on a 7.56 ha grid.

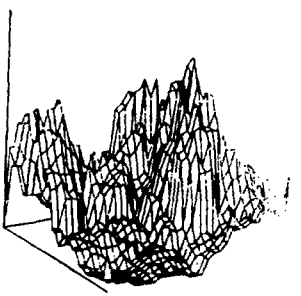

Fig. 10.35. Three-dimensional display showing the distribution of Hedyotis on a 7.56 ha grid.

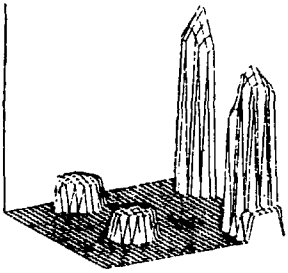

Fig. 10.36. Three-dimensional display showing the distribution of Chrysothamnus on a 7.56 ha grid.

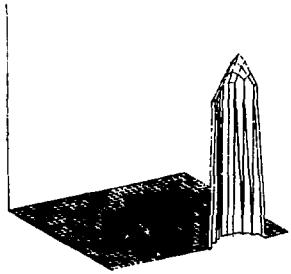

Fig. 10.37. Three-dimensional display showing the distribution of Haplopappus on a 7.56 ha grid.

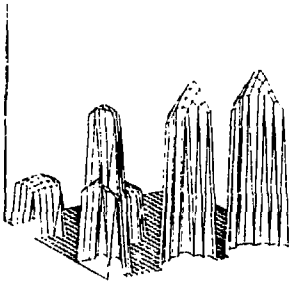

Fig. 10.38. Three-dimensional display showing the distribution of Heterotheca on a 7.56 ha grid.

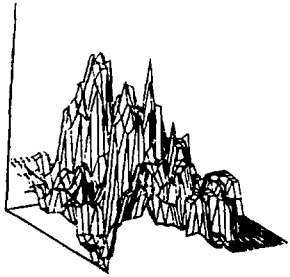

Fig. 10.39. Three-dimensional display showing the distribution of Pectis on a 7.56 ha grid.

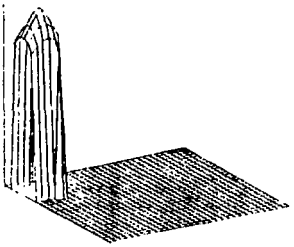

Fig. 10.40. Three-dimensional display showing the distribution of Hymenopappus on a 7.56 ha grid.

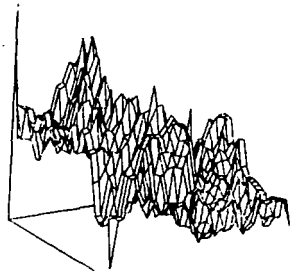

Fig. 10.41. Three-dimensional display showing the distribution of Artemisia on a 7.56 ha grid.

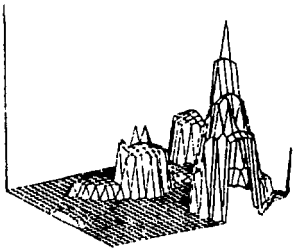

Fig. 10.42. Three-dimensional display showing the distribution of Senecio on a 7.56 ha grid.

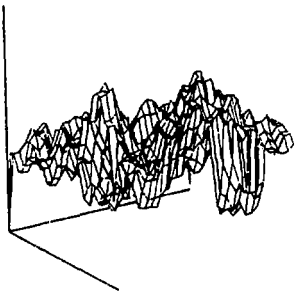

Fig. 10.43. Three-dimensional display showing the distribution of bare ground on a 7.56 ha grid.

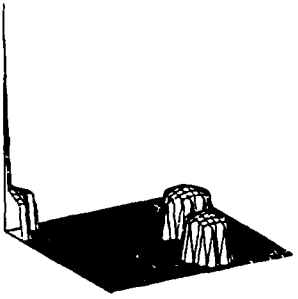

Fig. 10.44. Three-dimensional display showing the distribution of both sexes of spotted ground squirrels on a 7.56 ha grid.

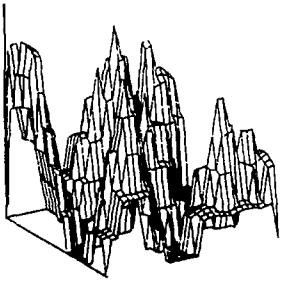

Fig. 10.45. Three-dimensional display showing the distribution of male Ord's kangaroo rats on a 7.56 ha grid.

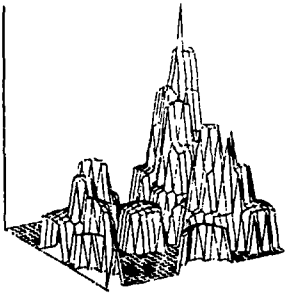

Fig. 10.46. Three-dimensional display showing the distribution of female Ord's kangaroo rats on a 7.56 ha grid.

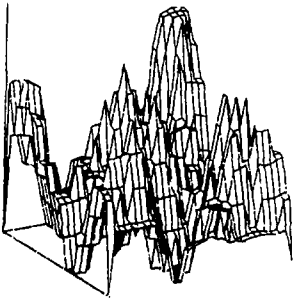

Fig. 10.47. Three-dimensional display showing the distribution of both sexes of Ord's kangaroo rats on a 7.56 ha grid.

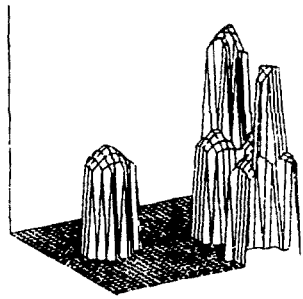

Fig. 10.48. Three-dimensional display showing the distribution of male northern grasshopper mice on a 7.56 ha grid.

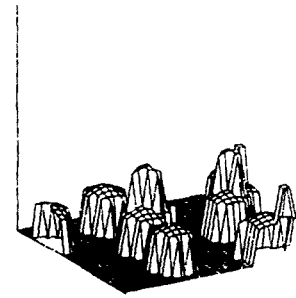

Fig. 10.49. Three-dimensional display showing the distribution of female northern grasshopper mice on a 7.56 ha grid.

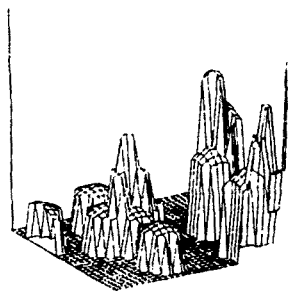

Fig. 10.50. Three-dimensional display showing the distribution of both sexes of northern grasshopper mice on a 7.56 ha grid.

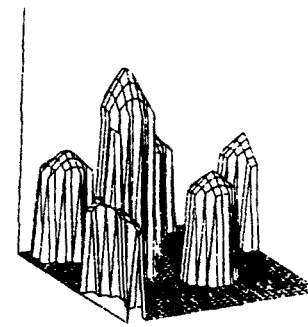

Fig. 10.51. Three-dimensional display showing the distribution of both sexes of southern plains woodrats on a 7.56 ha grid.

Table 10.1. Amphibian, reptilian, and mammalian species list for those species on or near the study area but not observed during this study. The species were reported in published materials.[10-18]

AMPHIBIANS

Couch's Spadefoot
Scaphiopus couchi
Baird

Western Spadefoot
Scaphiopus hammondi
Baird

Woodhouse's Toad
Bufo woodhousei
Girard

Red-spotted Toad
Bufo punctatus
Baird & Girard

Barking Frog
Eleutherodactylus augusti
(Duges)

Cricket Frog
Acris gryllus
Le Conte

Leopard Frog
Rana pipiens
Schreber

Bull Frog
Rana catesbeiana
Shaw

REPTILES

Common Snapping Turtle
Chelydra serpentina
Linnaeus

Pond Slider
Pseudemys scripta
(Schoepff)

Spiny Soft-shelled Turtle
Trionyx spiniferus
Lesueur

Eastern Fence Lizard
Sceloporus undulatus
(Latreille)

Sagebrush Lizard
Sceloporus graciosus
Baird & Girard

Checkered Whiptail
Cnemidophorus tessellatus
(Say)

Little Striped Whiptail
Cnemidophorus inornatus
Baird

Texas Blind Snake
Leptotyphlops dulcis
(Baird & Girard)

Plain-bellied Water Snake
Natrix erythrogaster
(Forster)

Checkered Garter Snake
Thamnophis marcianus
(Baird & Girard)

Common Garter Snake
Thamnophis sirtalis
(Linnaeus)

Corn Snake
Elaphe guttata
(Linnaeus)

Common King Snake
Lampropeltis getulus
Linnaeus

Ground Snake
Sonora episcopa
Kennicott

Western Hooked-nosed Snake
Ficimia cana
(Cope)

Great Plains Black-headed Snake
Tantilla nigriceps
Kennicott

MAMMALS

Desert Shrew
Notiosorex crawfordi
(Coues)

Yuma Myotis
Myotis yumanensis
(H. Allen)

Long-eared Myotis
Myotis evotis
(H. Allen)

Fringed Myotis
Myotis thysanodes
Miller

Long-legged Myotis
Myotis volans
(H. Allen)

California Myotis
Myotis californicus
(Audubon & Bachman)

Silver-haired Bat
Lasionycteris noctivagans
(Le Conte)

Western Pipistrelle
Pipistrellus hesperus
(H. Allen)

Big Brown Bat
Eptesicus fuscus
(Palisot de Beauvois)

Red Bat
Lasiurus borealis
(Muller)

Townsend's Big-eared Bat
Plecotus townsendii
Cooper

Brazilian Free-tailed Bat
Tadarida brasiliensis
(I. Geoffroy Saint-Hilaire)

Pocketed Free-tailed Bat
Tadarida femorosacca
(Merriam)

Big Free-tailed Bat
Tadarida macrotis
(Gray)

Plains Harvest Mouse
Reithrodontomys montanus
(Baird)

White-tailed Deer
Odocoileus virginianus
Zimmerman

Pronghorn
Antilocapra americana
(Ord)

Table 10.2. Cataloged amphibian, reptilian, and mammalian specimens from the WIPP vicinity. Data for the species listed below were collected from 29 August 1975 to 30 September 1978. Habitats where species occur are designated SOM = shinnery oak-mesquite, CG = creosote-grassland, MG = mesquite-grassland, MS = mesquite-snakeweed, ADL = active dune land, and A = aquatic (dirt or metal tank). All species are resident. All other symbols are explained in the footnotes.

Species	Habitat	Status Abundance	Observation record J	F	M	A	M	J	J	A	S	O	N	D
AMPHIBIANS:														
Tiger Salamander *Abystoma tigrinum* (Green)	A	C						S	O	S				
Plains Spadefoot *Scaphiopus bombifrons* Cope	A	C						S						
Texas Toad *Bufo speciosus* Girard	A	UC						O						
Great Plains Toad *Bufo cognatus* Say	A SOM	UC						S	O					
Green Toad *Bufo debilis* Girard	A	C						S		S				
REPTILES:														
Yellow Mud Turtle *Kinosternon flavescens* (Agassiz)	A	VC				O	O	O	O	S				
Western Box Turtle *Terrapene ornata* (Agassiz)	SOM MG ADL	VC	O		O		O	O	O	S		S		
Collared Lizard *Crotaphytus collaris* (Say)	MG	UC						O						
Leopard Lizard *Crotaphytus wislizeni* Baird and Girard	ADL SOM	UC					S	S	O	O				
Lesser Earless Lizard *Holbrookia maculata* Girard	SOM	UC				S		O	O	O	C			
Greater Earless Lizard *Holbrookia texana* (Troschel)	CG	UC				S	S		O	O				
Side-blotched Lizard *Uta stansburiana* Baird and Girard	SOM CG MG MS ADL	VC	O	O	C	S	S	S	S	S	C	C		O
Texas Horned Lizard *Phrynosoma cornutum* (Harlan)	SOM MG	UC			O	O	O	C	C	C	S	C		

Table 10.2. (Cont.)

Species	Habitat	Status Abundance	Observation record J	F	M	A	M	J	J	A	S	O	N	D
Round-tailed Horned Lizard *Phrynosoma modestum* Girard	MG	UC						S						
Western Whiptail Lizard *Cnemidophorus tigris* Baird and Girard	SOM CG ADL	C			S	S	S	S	S	S	S	C		
Six-lined Racerunner *Cnemidophorus sexlineatus* (Linnaeus)	SOM	UC					C	C	C	C				
Great Plains Skink *Eumeces obsoletus* (Baird and Girard)	SOM CG	UC						S						
Western Hognose Snake *Heteradon nasicus* Baird and Girard	SOM	C					O	O	O	O	S	O		
Coachwhip *Masticophis flagellum* (Shaw)	SOM	C				O	O	O	O	S	S			
Glossy Snake *Arizona elegans* Kennicott	SOM	C					O	O	O					
Bullsnake *Pituophis melanoleucus* (Schlegel)	SOM	C				O	O	O	O	O	S	O		
Long-nosed Snake *Rhinocheilus lecontei* Baird and Girard	SOM	UC							S					
Night Snake *Hypsiglena torquata* Gunther	SOM	UC									S			
Massasauga *Sistrurus catenatus* (Rafinesque)	SOM	UC				O	S	O	O					
Western Diamondback Rattlesnake *Crotalus atrox* Baird and Girard	SOM CG	UC						S	O	O	S			
Western Rattlesnake *Crotalus viridis* (Rafinesque)	SOM CG	C				O			O	S	S		O	
BATS:														
Cave Myotis *Myotis velifer* (J. A. Allen)	A	C						S	S					

Table 10.2. (Cont.)

Species	Habitat	Status Abundance	Observation record J	F	M	A	M	J	J	A	S	O	N	D
Pallid Bat *Antrozous pallidus* (Le Conte)	A	UC						S	S					
LAGOMORPHS:														
Blacktail Jackrabbit *Lepus californicus* Gray	SOM MG CG MS ADL	VC	O	O	C	C	C	C	C	C	O	O	O	O
Desert Cottontail *Sylvilagus auduboni* (Baird)	SOM MG CG MS ADL	VC	O	O	S	S	S	S	S	S	S	O	O	O
RODENTS:														
Mexican Ground Squirrel *Spermophilus mexicanus* (Erxleben)	CG	UC								S				
Spotted Ground Squirrel *Spermophilus spilosoma* Bennett	SOM	VC			S	S	S	S	S	S	S	C	O	
Plains Pocket Gopher *Geomys bursarius* (Shaw)	SOM	C									S			
Yellow-faced Pocket Gopher *Pappogeomys castanops* (Baird)	CG	UC							S					
Silky Pocket Mouse *Perognathus flavus* Baird	SOM MG CG MS	C		O	O			S	S	S		C	S	
Plains Pocket Mouse *Perognathus flavescens* Merriam	SOM MG	C	S				O	S	S	S	S	S	S	
Hispid Pocket Mouse *Perognathus hispidus* Baird	MG MS	UC											S	O
Desert Pocket Mouse *Perognathus penicillatus* Woodhouse	ADL CG SOM	C						S		S				
Ord's Kangaroo Rat *Dipodomys ordii* Woodhouse	SOM MS ADL MG	VC	S	S	S	S	S	S	S	S	S	S	O	S
Bannertail Kangaroo Rat *Dipodomys spectabilis* Merriam	MG CG MS	VC	S	S			I		O			S	O	I
Merriam Kangaroo Rat *Dipodomys merriami* Mearns	MS ADL CG MG	VC	S	S			O		O	S	S		O	O

Table 10.2. (Cont.)

Species	Habitat	Status Abundance	Observation record J	F	M	A	M	J	J	A	S	O	N	D
Western Harvest Mouse *Reithrodontomys megalotis* (Baird)	MG CG	UC		O	O					S				
Deer Mouse *Peromyscus maniculatus* (Wagner)	SOM	UC					O	S	C	O				
White-footed Mouse *Peromyscus leucopus* (Rafinesque)	SOM MG CG ADL	C								O				
Northern Grasshopper Mouse *Onychomys leucogaster* (Wied-Neuwied)	SOM CG MG MS ADL	VC	S									S	S	S
Hispid Cotton Rat *Sigmodon hispidus* Say and Ord	SOM MG CG	C	O	O	O	O		O				O	O	
Southern Plains Woodrat *Neotoma micropus* Baird	SOM ADL MG MS CG	VC	O		C							C	O	O
White-throated Woodrat *Neotoma albigula* Hartley	MG CG	C	S	S				O		O				
Porcupine *Erethizon dorsatum* (Linnaeus)	SOM MG MS	C		O				O		O	I	I		
CARNIVORES:														
Coyote *Canis latrans* Say	SOM CG MG MS ADL	VC	O	O	I	O	O	O	O	O	O	O	O	O
Swift Fox *Vulpes velox* (Say)	CG	UC						O						
Badger *Taxidea taxus* (Schreber)	SOM MG	C				O	I	O	O	O	I	I		
Striped Skunk *Mephitis mephitis* (Schreber)	SOM	C					I				I	O		
Bobcat *Lynx rufus* (Schreber)	SOM	UC							O		S			
UNGULATES:														
Mule Deer *Odocoileus hemionus* (Rafinesque)	SOM	VC	O	I	O	O	O	O	O	O	O	I		O

Table 10.2. (Cont.)

STATUS

A = abundance
VC = very common; abundant
C = common; regularly present, abundant but sporadic occurrence
UC = uncommon; seen once, evidence that species is present
J = counted on the survey sites. See Tables 10.8 and 10.14 for densities.

OBSERVATION RECORD

Observations are presented for each month from August 1975 to September 1978

S = specimen(s) collected
C = species counted
O = species observed but not counted
T = tracks, vocalizations, or other recent signs indicative of presence of species

Table 10.3. Census results of lizard surveys in the shinnery oak-mesquite habitat in 1978. Numbers in parentheses refer to the number of days in the census.

Species and age class	April (4)		May (3)		June (3)		July (4)		August (2)	
	No.	No./ha	No.	No./ha	No.	No./ha	No.	No./ha	No.	No./ha
Side-blotched Lizard										
Adults	56	14.0	20	6.7	11	3.7	20	5.0	5	2.5
Juveniles[a]	1	0.3	0	0	0	0	7	1.8	13	6.5
Total	57	14.3	20	6.7	11	3.7	27	6.8	18	9.0
Western Whiptail Lizard										
Adults	0	0	10	3.3	8	2.7	9	2.3	3	1.5
Juveniles	0	0	0	0	0	0	0	0	0	0
Total	0	0	10	3.3	8	2.7	9	2.3	3	1.5
Six-lined Racerunner										
Adults	0	0	3	1.0	8	2.7	8	2.0	3	1.5
Juveniles	0	0	0	0	0	0	0	0	0	0
Total	0	0	3	1.0	8	2.7	8	2.0	3	1.5
Unidentified	0	0	0	0	0	0	1	0.3	0	0
Total	57	14.3	33	11	27	9	45	11.3	24	12.0

[a]Juveniles observed in the spring were hatched the previous summer; juveniles observed during the 1978 summer were hatched that summer.

Table 10.4. Densities of lizards on a 1 ha grid in shinnery oak-mesquite during 1976, 1977, and 1978. Numbers above the slash marks are adults; numbers below the slash marks are juveniles.

Species	1976[a]			1977[b]			1978		
	June	July	August	June	July	August	June	July	August
Side-blotched Lizard	13.6/0	13.8/8.2	8.5/8.2	6.8/0	3.8/1.7	2.3/2.0	3.7/0	5.0/1.8	2.5/6.5
Western Whiptail Lizard	4.9/0	3.4/0	1.9/0	2.3/0	0.8/0	0.7/0	2.7/0	2.3/0	1.5/0
Six-lined Racerunner	0.1/0	0/0	0.1/0	0.7/0	0.3/0	0/0	2.7/0	2.0/0	1.5/0

[a]Gennaro and Jorgensen (1977)

[b]Gennaro and Jorgensen (1978)

Table 10.5. Collecting periods, numbers of trap nights, percentages of trap success, numbers of Ord's kangaroo rats captured, and number of other species of small mammals captured on the small mammal removal site during 1978.

Collecting periods	Trap nights	Percentage trap success	No. Ord's Kangaroo Rats	No. other small mammalian species
March 11-25	2803	2.10	37	22
April 7-9, 14-16	1344	6.7	61	29
May 5-6, 11-12, 15-21	2566	4.0	59	43
June 1-14	3625	1.7	30	33
June 27-30	1850	5.1	58	37
July 29-30 August 1-12	5679	0.9	32	21
August 25-27 September 1-4, 8-10	3843	1.7	33	31

Table 10.6. Collecting periods, number of trap days, percentage trap success, and number of spotted ground squirrels (*Spermophilus spilosoma*) collected during 1978.

Collecting periods	Trap days	Percentage trap success	No. specimens collected
March 11-25	2836	0.2	5
April 8-9, 15	869	0.1	1
May 5-6, 11-12, 15-21	2676	0.3	7
June 4-8, 13	2450	0.1	2
June 27-30 July 1, 6, 15-16	2600	0.2	5
July 29-31, August 1-12	5004	0.4	20
August 25, Sept. 2, 4	2011	1.3	27

Table 10.7. Collecting periods and numbers of the desert cottontail (*Sylvilagus audubonii*) collected during 1978.

Collecting periods	No. specimens collected
March 24-26	5
April 15	2
May 19, 20, 25	3
June 3, 5, 7-9	10
June 29, 30 July 1, 4	10
August 3, 5, 6	11

Table 10.8. Small mammal census data from the 90 by 90 m study grid.

Species	N[a]	N_m	D	$\bar{W}$	B	M	F	RS 1	RS 2	RS 3	RS 4
March Trapping Periods											
Spotted Ground Squirrel	1.0	2	1.2	90.5	108.6	1	0	0	0	1	0
Plains Pocket Mouse	3.0	5	1.1	9.7	10.7	1	0	0	1	0	0
Ord's Kangaroo Rat	24.8	37[b]	13.4	56.7	759.8	20	17	0	15	12	10
Northern Grasshopper Mouse	12.8	16[c]	5.7	46.9	267.3	9	7	0	5	6	5
Southern Plains Woodrat	0	0	0	0	0	0	0	0	0	0	0
June Trapping Periods											
Spotted Ground Squirrel	19.5	16[d]	8.4	121.2	1018.1	9	7	1	3	12	0
Plains Pocket Mouse	12.7	5	3.9	11.0	78.1	1	4	0	5	0	0
Ord's Kangaroo Rat	37.5	27	15.5	64.3	996.7	17	10	0	10	13	4
Northern Grasshopper Mouse	6.7	6	1.7	42.7	72.6	4	2	1	1	3	1
Southern Plains Woodrat	2.0	2	0.7	201.0	60.3	2	0	1	0	1	0

[a] N = estimated number of individuals (Hayne 1949)
N_m = number of individuals marked
D = density per ha
$\bar{W}$ = mean weight (g)
B = biomass (g/ha)
M = number of males
F = number of females
RS = reproductive status: 1-immature; 2-inactive adults; 3-active adults (includes lactating females); 4- pregnant females

[b] Eleven specimens died.
[c] Four specimens died.
[d] Three specimens died.

Table 10.9. Density, biomass, and average movements of small mammals on the 90 by 90 m grid for 3 years.

Species	June 1976[a]			June 1977[b]			June 1978		
	No./ha	g/ha	Average movements	No./ha	g/ha	Average movements	No./ha	g/ha	Average movements
Spotted Ground Squirrel	4	511.2	38	7.7	749.2	30.5	8.4	1018.1	31.2
Plains Pocket Mouse	14.2	149.1	15	11.5	112.7	36.0	7.1	78.1	22
Ord's Kangaroo Rat	20.5	1152.1	15	22.5	1305.0	19.9	15.5	996.7	32.7
Northern Grasshopper Mouse	5.2	201.8	34	4.3	168.1	38.5	1.7	72.6	53
Southern Plains Woodrat	0.7	124.6	14	0	0	0	0.3	60.3	83

[a]Gennaro and Jorgensen (1977)

[b]Gennaro and Jorgensen (1978)

Table 10.10. Small mammal recapture success (R) for the 90 by 90 m grid during 1978.[a]

Species	15-19 March First trapping period R	%	23-27 March Second trapping period[b] R	%	6-10 June First trapping period R	%	14-18 June Second trapping period R	%
Spotted Ground Squirrel	0/0	0	1/1	100	5/12	41	5/16	31
Plains Pocket Mouse	1/1	100	1/1	100	0/2	0	1/5	20
Ord's Kangaroo Rat	19/27	70	16/37	43	9/21	75	3/27	11
Northern Grasshopper Mouse	9/13	69	4/16	25	2/5	40	1/6	16
Southern Plains Woodrat	0/0	·	0/0	0	1/2	50	0/2	0

[a]Recapture success (R) is the number of animals recaptured relative to the number of animals marked.

[b]The number of captures during the second period are the total number of captures for both periods, but the number of recaptures during the second period apply only to that period.

Table 10.11. Average movements (m) of small mammals on the 90 by 90 m study grid during 1978. The trapping periods are 15-19 March, 23-27 March, 6-10 June, and 14-18 June.

Species	March trapping periods Sample size	Mean	Range	June trapping periods Sample size	Mean	Range
Spotted Ground Squirrel	0	0	0	13	31.2	10-56
Plains Pocket Mouse	3	37.7	30-53	1	0	0
Ord's Kangaroo Rat	43	23.0	10-70	15	32.7	10-110
Northern Grasshopper Mouse	9	29.7	10-44	3	53	10-79
Southern Plains Woodrat	0	0	0	1	0	0

Table 10.12. Correlation coefficients (n = 144) between mammals captured on the 275 by 275 m (7.56 ha) grid and plant genera on that grid. Numbers in parentheses following the mammal species indicates the number of stations where the species was encountered; numbers in parentheses following the plant genera and bare ground indicate the number of stations where they were encountered.

Species	Both sexes Spotted Ground Squirrel (3)	Male Ord's Kangaroo Rat (37)	Female Ord's Kangaroo Rat (21)	Both sexes Ord's Kangaroo Rat (58)	Male Northern Grasshopper Mouse (8)	Female Northern Grasshopper Mouse (9)	Both sexes Northern Grasshopper Mouse (17)	Both sexes Southern Plains Woodrat (5)
Leptoloma (70)	.016	-.116	.037	-.070	.160*	.011	.110	-.085
Brachiaria (1)	-.012	-.046	.202**	.095	-.019	-.023	-.025	.306**
Paspalum (70)	-.108	-.080	.048	-.029	.018	-.076	-.028	[illegible]
Setaria (3)	-.023	-.088	.025	-.059	-.036	-.044	-.047	[illegible]
Cenchrus (33)	-.063	-.027	-.058	-.057	-.029	.065	.035	-.058
Erioneuron (102)	-.065	.030	-.068	-.033	-.063	-.074	-.074	-.068
Sporobolus (126)	-.045	-.108	-.035	-.115	.026	.117	.062	.079
Muhlenbergia (2)	-.017	.111	-.047	.068	-.026	-.031	-.034	[illegible]
Bouteloua (1)	-.012	-.046	.202**	.095	-.019	-.023	-.025	[illegible]
Aristida (131)	-.099	.136	-.099	.062	-.100	.126	.009	[illegible]
Cyperus (1)	-.012	-.046	-.035	-.063	-.019	-.023	-.025	-.018
Yucca (42)	.076	-.129	-.159*	-.206**	-.019	.047	.031	[illegible]
Quercus (140)	.173*	-.090	.107	-.002	-.024	.039	.008	[illegible]
Eriogonum (10)	-.029	.028	-.028	.009	-.056	-.055	-.060	[illegible]
Mirabilis (2)	-.017	-.063	.075	-.005	-.026	-.031	[illegible]	[illegible]
Dithyrea (11)	-.034	.076	-.079	.017	.196**	.157*	.217**	[illegible]
Mimosa (1)	-.017	.075	.100	.011	-.027	-.032	-.035	[illegible]
Prosopis (19)	-.013	-.056	-.035	-.062	-.017	.196**	.199**	[illegible]
Caesalpinia (8)	[illegible]	[illegible]	.106	.028	.150*	[illegible]	.039	[illegible]
Dalea (22)	.003	-.196	.042	-.063	-.064	.161*	.078	[illegible]
Phyllanthus (1)	-.012	-.046	-.035	-.063	-.019	-.023	[illegible]	[illegible]
Croton (10)	-.033	-.087	.014	-.064	-.031	-.064	[illegible]	[illegible]
Euphorbia (12)	-.040	-.066	-.001	-.055	-.062	.083	.035	[illegible]
Mentzelia (4)	-.021	.024	-.060	-.017	-.033	-.040	-.043	[illegible]
Calylophus (4)	-.024	-.090	.310**	.129	.006	-.043	.033	[illegible]

Table 10.12. (Cont.)

Species	Both sexes Spotted Ground Squirrel (5)	Male Ord's Kangaroo Rat (37)	Female Ord's Kangaroo Rat (21)	Both sexes Ord's Kangaroo Rat (58)	Male Northern Grasshopper Mouse (8)	Female Northern Grasshopper Mouse (9)	Both sexes Northern Grasshopper Mouse (17)	Both sexes Southern Plains Woodrat (5)
Gaura (2)	-.012	.133	-.035	.095	-.019	-.023	-.025	-.018
Phacelia (1)	-.012	-.046	-.035	-.063	-.019	.306**	.198**	-.018
Heliotropium (23)	-.011	-.001	-.079	-.065	-.039	.109	.058	.048
Monarda (4)	-.023	-.088	-.066	-.120	-.036	.053	.018	-.035
Solanum (1)	-.012	-.046	-.035	-.063	-.019	-.023	-.025	-.018
Penstemon (17)	-.027	-.023	.136*	.073	-.043	-.051	-.056	-.041
Hedyotis (103)	-.094	-.008	.041	.017	-.042	-.027	-.043	-.083
Chrysothamnus (0)	-.022	-.035	.081	.025	-.033	-.040	-.044	-.032
Haplopappus (1)	-.012	-.046	-.035	-.063	-.019	-.023	-.025	-.018
Heterotheca (6)	-.027	-.102	-.004	-.090	-.042	-.051	-.055	.060
Pectis (64)	.005	.058	-.137*	-.048	-.020	-.068	-.040	-.076
Hymenopappus (1)	-.012	-.046	-.035	-.063	-.019	-.023	-.025	-.018
Artemisia (116)	-.031	.050	-.179*	-.087	.018	.010	.001	-.093
Senecio (13)	-.036	-.002	.171*	.115	-.056	-.034	-.050	-.053
Bare ground (153)	-.075	.009	.010	.012	-.076	-.045	-.048	-.173*

* P < 0.05 ** P < 0.01

Table 10.13. Summary of daily trapping success for small mammals on the 275 by 275 m (7.56 ha) grid in July 1978. The letter M refers to the inner grid.

Date	Species	No. recaptured/grid					New captures/grid				
		M	X	Y	Z	Total	M	X	Y	Z	Total
20 July	Ord's Kangaroo Rat	0	0	0	0	0	15[a]	2	2	15	34
	Northern Grasshopper Mouse	0	0	0	0	0	2	1	0	0	3
21 July	Ord's Kangaroo Rat	7	1	5	5	18	0	0	0	3	3
	Northern Grasshopper Mouse	2	0	1	0	3	2	0	1	0	3
22 July	Ord's Kangaroo Rat	13	3	2	12	30	2	0	0	2	4
	Northern Grasshopper Mouse	0	0	0	0	0	0	0	0	1	1
	Southern Plains Woodrat	0	0	0	0	0	0	0	0	1	1
23 July	Ord's Kangaroo Rat	5	3	3	10	21	0	0	0	1	1
	Northern Grasshopper Mouse	1	0	0	1	2	2	0	1	2	5
	Southern Plains Woodrat	0	0	0	0	0	0	0	0	1	1
24 July	Ord's Kangaroo Rat	10	3	2	8	23	0	0	0	4	4
	Northern Grasshopper Mouse	2	0	0	1	3	0	0	1	0	1
	Southern Plains Woodrat	0	0	0	0	0	1	0	0	0	1
25 July	Ord's Kangaroo Rat	5	1	0	7	13	0	0	0	0	0
	Northern Grasshopper Mouse	1	1	0	2	4	0	0	0	1	1
	Southern Plains Woodrat	0	1	0	0	1	0	1	0	3	4
26 July	Ord's Kangaroo Rat	4	3	0	8	15	0	0	0	0	0
	Northern Grasshopper Mouse	1	0	0	2	3	0	0	0	0	0
	Southern Plains Woodrat	0	0	1	0	1	0	0	0	0	0
	Plains Pocket Mouse	0	0	0	0	0	0	0	0	1	1
27 July	Ord's Kangaroo Rat	6	3	4	6	19	0	0	0	0	0
	Northern Grasshopper Mouse	3	1	0	3	7	0	0	0	2	2
	Southern Plains Woodrat	1	0	0	0	1	1	0	0	1	2
28 July	Ord's Kangaroo Rat	3	3	0	4	10	0	0	0	0	0
	Northern Grasshopper Mouse	1	0	0	0	1	1	0	0	2	3
	Southern Plains Woodrat	0	0	1	0	1	0	0	0	0	0
	Plains Pocket Mouse	0	0	0	0	0	0	0	0	1	1
29 July	Ord's Kangaroo Rat	1	2	1	2	6	1	0	0	1	2
	Northern Grasshopper Mouse	3	2	0	0	5	0	0	0	0	0
	Southern Plains Woodrat	0	0	2	1	3	1	0	0	0	1

[a]One animal died (no tag)

Table 10.14. Densities of small mammals on the 275 by 275 m (7.56 ha) grid in July 1978.

Species	No. marked		Estimated no. of individuals[a]	Density/ha
	Males	Females		
Ord's Kangaroo Rat	10	8	16.1	1.4
Northern Grasshopper Mouse	3	4	7.2	0.4
Southern Plains Woodrat	1	2	7.0	0.7

[a]Hayne (1949)

Table 10.15. Movement (m) of small mammals on the 275 by 275 m (7.56 ha) grid in July 1978.

Species	n	Mean	St. dev.	Range
Male Ord's Kangaroo Rat	34	38.2	23.4	0-100
Female Ord's Kangaroo Rat	22	29.6	23.8	0-90.1
Both sexes Ord's Kangaroo Rat	56	34.8	23.7	0-100
Male Northern Grasshopper Mouse	7	58.9	46.9	0-111.8
Female Northern Grasshopper Mouse	5	98.1	45.1	35.4-152.1
Both sexes Northern Grasshopper Mouse	12	75.2	48.5	0-152.1
Both sexes Southern Plains Woodrat	2	25.0	35.4	0-50

Table 10.16. Average home range in square meters occupied by small mammals on the 275 by 275 m (7.56 ha) grid in 1978.

Species	n	Mean	St. dev.	Range
Male Ord's Kangaroo Rat	8	864.5	348.5	616-1366
Female Ord's Kangaroo Rat	6	807.7	569.6	308-1498
Both sexes Ord's Kangaroo Rat	14	840.1	437.0	308-1498
Male Northern Grasshopper Mouse	1	3890.0	000.0	--------
Female Northern Grasshopper Mouse	2	4559.5	3208.1	2291-6828
Both sexes Northern Grasshopper Mouse	3	4336.3	2301.2	2291-6828

Table 10.17. Comparison of lagomorph densities for 2 years (1977[a] and 1978) from the 1 km^2 (100 ha) study site. Numbers above the slash marks are 1977 densities; numbers below the slash marks are 1978 densities.

Species	March	April	May	June	July	August
Black-tailed Jackrabbit	5.3/4.3	16.7/21	15.4/10	13.6/15.7	21.6/23.2	16.3/25.5
Desert Cottontail	2.7/2.6	2.3/5	5.3/3	7.1/0.7	5.1/2.8	2/5

[a] Gennaro and Jorgensen (1978)

Table 10.18. Harvest data for mule deer from eastern Eddy and southern Lea counties.

Unit[a]	Year	Harvest	95% Conf. Interval	Hunter Pressure	% Hunter Success	Days/Deer Killed
31	1977	10	231.0	200	5.00	43.00
31	1976	22	145.1	228	9.60	21.00
61	1975	19	158.6	264	7.20	24.50
61	1974	60	92.4	517	11.60	23.40
61	1973	71	86.4	380	18.68	12.33
61	1972	55	99.2	342	16.08	18.40
61	1971	65	99.6	189	34.39	3.20
61	1970	15	206.8	30	50.00	20.00
61	1969	16	207.5	16	100.00	4.00
61	1968	15	196.3	17	88.20	1.00
61	1967	13	242.6	27	48.10	9.00

[a]Unit numbers refer to the attached maps. Prior to 1976 the WIPP area was in game management unit number 61, now it is in unit 31.

Table 10:19. Relative predator abundance indices from two survey indices from two survey routes in southeastern New Mexico. Part of route 23 was within the 5 mile radius area around ERDA 9. Route 24 was about 12 miles south of the 5 mile radius boundry. Numbers above the slash marks are indices from survey route 23; numbers below the slash marks are indices from survey route 24.

Species	1972	1973	1974	1975	1976	1977	1978[b]
Coyote	44/137	53/96	40/44	21/40	10/57	25/45	40/55
Gray Fox	0/0	0/0	0/0	7/0	0/0	0/0	0/0
Kit Fox[a]	0/0	0/0	0/0	0/5	0/0	0/0	0/0
Racoon	4/0	0/0	0/0	0/0	0/0	0/0	0/0
Badger	4/4	16/0	4/0	0/20	10/11	0/5	5/15
Skunk	0/0	8/4	8/0	0/5	0/6	0/0	10/0
Bobcat	0/4	0/4	0/0	0/0	0/0	0/0	0/0

[a] The reports refer to the Kit Fox (Vulpes macrotus), but tracks along route 23 or 24 could be also those of the Swift Fox (Vulpes velox).

[b] Data were obtained by personal communcation from Denver Wildlife Research Center, Colorado.

Table 10.20. Frequency (%) of flowering plant species on the 1 ha lizard study site. Results are based upon an analysis of points spaced at 2 m intervals along transects run within the study site, 200 points/sample date. Also listed are the frequencies of those points which did not come in contact with plant species; these are categorized as either exposed surface soil areas or soil surface areas which contained appreciable amounts of plant litter. Location: T22S R31E, NE 1/4 Sec 21.

Species	Sample dates		
	31 May 1978	26 July 1978	13 August 1978
Aristida purpurea Nutt.	10.0	16.5	12.0
Artemisia filifolia Torr.	4.0	4.5	7.0
Bouteloua eriopoda (Torr.)	1.5	6.0	5.5
Croton dioicus Cav.	4.0	5.5	11.0
Cyperus uniflorus T.&H.	0	0.5	0
Eragrostis intermedia Hitch.	0	1.0	4.5
Eragrostis oxylepis (Torr.)	0	0	0.5
Hoffmanseggia jamesii (T. & G.)	0.5	0	0
Melampodium leucanthum T. & G.	0.5	0	1.0
Munroa squarrosa (Nutt.)	0	2.0	1.5
Panicum sp. L.	1.0	0	0
Panicum arizonicum Scribn. & Merr.	0	0	1.0
Panicum capillare L.	0	3.0	0.5
Paspalum setaceum Michx.	0	1.0	0
Prosopis glandulosa Torr.	1.5	2.0	3.0
Quercus havardii Rydb.	18.0	15.5	14.0
Solanum elaeagnifolium Cav.	0	0.5	0.5
Sporobolus flexuosus (Thurb.)	2.5	6.5	5.0
Xanthocephalum sarothrae (Pursh.)	0	0.5	0
Yucca campestris McKelvey	1.0	0.5	0.5
Exposed Soil Surface	28.0	25.0	27.5
Soil Surface with Litter	24.0	24.0	15.0

Table 10.21. Frequency (%) of flowering plant species on the 90 by 90 m mammal grid. Results are based upon an analysis of points spaced at 2 m intervals along transects run within the study site, 200 points/sample date. Also listed are the frequencies for those points which did not come in contact with plant species; these are categorized as either exposed surface soil areas or soil surface areas which contained appreciable amounts of plant litter. Location: T22S R31E, NE 1/4 Sec 21.

Species	Sample dates 25,27 March 1978	5 June 1978
Aristida purpurea Nutt.	9.5	7.0
Artemisia filifolia Torr.	6.0	5.0
Bouteloua eriopoda (Torr.)	0	0.5
Cenchrus incertus M.A. Curtis	0	2.0
Croton dioicus Cav.	1.5	0.5
Eragrostis intermedia Hitch.	1.0	0
Euphorbia parryi Engelm.	1.0	0
Hedyotis humifusa Gray.	8.0	2.0
Monarda citriodora Cerv.	1.0	0
Panicum so. L.	3.5	13.5
Paspalum setaceum Michx.	2.5	1.5
Pectis angustifolia Torr.	0	2.0
Prosopis glandulosa Torr.	4.0	4.0
Quercus havardii Rydb.	16.5	19.0
Senecio multicapitatus	3.0	0.5
Sporobolus flexuosus (Thurb.)	4.5	5.5
Yucca campestris McKelvey	4.0	1.5
Exposed Soil Surface	25.0	29.5
Soil Surface with Litter	16.5	15.0

Table 10.22. Frequency (%) of occurrence of flowering plant species on the small mammal removal sites. Results are based upon an analysis of points spaced at 2 m intervals along transects run within each removal site, 200 points/sample date. Also listed are the frequencies for those points which did not come in contact with plant species; these are categorized as either exposed surface soil areas or soil surface areas which contained appreciable amounts of plant litter. Sampling Period: March-August 1978.

Species	T 22S R 30E NW 1/4 S 13 27 March	T 22S R 31E NW 1/4 S 33 16 April	T 22S R 31E NW 1/4 S 31 20 May	T 22S R 31E SW 1/4 S 1 3 June	T 22S R 31E SE 1/4 S 33 2 July	T 22S R 31E SE 1/4 S 31 11 August
Aristida purpurea Nutt.	9.5	4.5	3.0	1.0	9.0	6.0
Artemisia tridentata Torr.	7.5	2.0	1.0	7.5	6.5	4.0
Calylophus drummondianus Spach.	0	0	0	0	1.0	1.5
Cenchrus incertus M. A. Curtis	2.5	1.0	1.0	0.5	1.5	0.5
Condalia ericoides (Gray) M. C. Johnst.	0	0	0.5	0	0	0
Croton dioicus Cav.	0	0	0	1.0	0	0
Cyperus uniflorus T & H	0	0	0	0	0.5	0
Eragrostis intermedia Hitch.	0	0	0.5	0	0	0
Eriogonum annuum Nutt.	2.0	0	0	0	0	1.5
Euphorbia parryi Engelm.	0	0	0	0	0.5	6.5
Bouteloua barbata Gray.	2.5	0	0	9.0	0	0
Helianthus annuus L.	0	0	0	0.5	0	0
Heliotropium convolvulaceum (Nutt.)	0	0	0	0	0.5	4.0
Hoffmanseggia jamesii (T. & G.)	0	0	0	0.5	0	0
Linum rigidum Pursh.	0	0	0	0	1.0	0
Monarda citriodora Cerv.	0.5	0.5	0.5	0	0	0
Munroa squarrosa (Nutt.)	0	0	0	0	0	2.0
Oenothera engelmannii (Small)	0	0	0	0.5	0	0
Panicum sp. 1.	2.0	0.5	0	0.5	0.5	0
Panicum capillare L.	0	0	0	0	1.5	1.5
Paspalum setaceum Michx.	0.5	0	0	0	0	0
Pectis angustifolia Torr.	0	0	0	0	0.5	0.5
Penstemon buckleyi Penn.	0	0	0	0.5	0	0

Table 10.22. (Cont.)

Species	Site locations, and sampling dates					
	T 22S R 30E NW 1/4 S 13 27 March	T 22S R 31E NW 1/4 S 33 16 April	T 22S R 31E NW 1/4 S 31 20 May	T 22S R 31E SW 1/4 S 1 3 June	T 22S R 31E SE 1/4 S 33 2 July	T 22S R 31E SE 1/4 S 31 11 August
Phacelia integrifolia Torr.	0	0	0	0.5	0	0
Prosopis glandulosa Torr.	0.5	11.5	7.0	5.0	10.0	4.5
Quercus havardii Rydb.	30.5	18.5	11.0	23.5	30.5	32.5
Senecio multicapitatus	3.0	1.5	0	0.5	0	0
Solanum elaeagnifolium Cav.	0	0	0	0.5	0	0
Sporobolus flexuosus (Thurb.)	3.0	0	1.0	3.5	9.5	10.0
Xanthocephalum sarothrae (Pursh.)	0	8.0	5.5	4.0	4.0	1.5
Yucca campestris McKelvey	2.5	2.5	2.0	11.0	0.5	1.5
Exposed Soil Surface	27.0	42.5	37.0	31.0	32.5	29.5
Soil Surface with Litter	16.5	10.5	31.5	12.0	2.0	9.0

Table 10.23. Total plant frequencies (%) /sampling date (TF), the total number of points (%) which did not come in contact with live plants along each transect (includes both exposed and litter-covered surfaces) (NCP), and the TF/NCP ratios for each sample date. Sampling Period: March-August 1978.

	Small Mammal Removal Sites (Sample Dates)						Lizard Study Site (Sample Dates)			Live Mammal Site (Sample Dates)	
Type of Information	27 March	16 April	20 May	3 June	2 July	11 August	31 May	26 July	13 August	25-27 March	5 June
Total Plant Frequency/ Sample Date (TF)	66.5	50.5	33.0	70.0	77.5	78.0	44.5	65.5	67.5	66.0	64.5
Total Non-Contact Points/ Sample Date (NCP)	43.5	53.0	68.5	43.0	34.5	38.5	52.0	49.0	42.5	41.5	44.5
TF/NCP Ratio	1.53	0.95	0.48	1.63	2.25	2.03	0.86	1.34	1.59	1.59	1.45

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CHAPTER 11

BATS OF THE LOS MEDAÑOS WIPP SITE

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Introduction

Findley et al report that 15 species of bats occur in Eddy County.[1] While none of these bats were found in the Los Medaños study area, three species (Myotis velifer, Antrozous pallidus, and Tadarida brasiliensis) were collected at Carlsbad, approximately 40 km west of Los Medaños. Records of the remaining 12 species (Myotis yumanensis, M. leibii, M. thysanodes, M. californicus, Lasionycteris noctivagans, Pipistrellus hesperus, Eptesicus fuscus, Lasiurus borealis, L. cinereus, Plecotus townsendii, Tadarida femorosacca, and T. macrotis) are confined to the western or southwestern portions of Eddy County. No bats have been reported from Lea County, the western border of which lies in the eastern section of the study area. However, 9 females and 1 male Myotis velifer were captured in May 1975 and May 1976, respectively, at Bell Lake, Lea Country, approximately 19 km east of Los Medaños.[2]

Materials and Methods

Bats were collected by placing mist nets at cattle tanks in and around the study area (Fig. 11.1). Netting was conducted on 17 of 19 field nights, with high winds and rain preventing netting on the remaining two nights (Table 11.1). Six of the eight tanks in the area were netted at least once. Noye Tank was not netted because it was inaccessible during most of the study and was too large to be netted effectively. Divide Tank (metal) also was not netted because the water level was consistently too low for effective placement of the nets.

The mist nets used were 5-panel, 1-1/4-in mesh, ranging in lengths from 5.5 to 18.9 m. Nets were set by 1830 h, and monitored continuously until 2100 h. Nets remained in place throughout the night, and were checked between 0500 and 0600 the following morning. However, on five occasions the presence of cattle in the immediate area of the tanks necessitated removal of the nets at 2100 h. At Red Tank (June 13 and 14) and at Hill Tank (all dates), small pools of standing water were netted rather than the actual tanks, since these afforded more effective net placement.

Representative bats were collected and preserved as study skins and skeletons (see Table 11.2 for a list of specimens). After six animals of one species and sex were collected, additional captured bats were marked via a three-hole triangle punched in the plagiopatagium of each wing. They were then weighed, sexed, and released.

Results

Capture Success

A total of 58 bats (57 new animals, 1 recapture) was netted during the 17 field nights (Table 11.3). Two species were collected: M. velifer (cave myotis)--4 males, 34 females, and 3 of unknown sex--and A. pallidus (pallid bat)--1 male, 9 females, and 1 of unknown sex. Six bats could not be identified due to escape or mud turtle predation.

Average weights, with sample sizes in parentheses, are as follows:

M. velifer	males	7.6 g (3)	females 11.1 g (20)
A. pallidus	males	15.5 g (1)	females 22.2 g (8)

Two bats (1 Myotis and 1 unknown) were collected at Red Tank on June 13. All other animals were captured at Hill Tank, which, due to the relatively high degree of capture success at that location, was netted on 10 of the 17 field nights in order to obtain sufficient numbers of animals,

particularly Antrozous, for study specimens. Bats were observed only at Hill Tank and Red Tank. All bats captured were adults, except for a juvenile male collected on July 15 at Hill Tank.

Reproduction

Since the study lasted slightly less than two months, data on reproduction are sketchy. All bats captured during June were females, while males of both species were recorded only in July. This suggests that both species were sexually segregated during the summer, with females and young occupying nursery roosts. This has been reported previously for both Antrozous[3] and M. velifer.[1]

All female Antrozous were lactating. Both female Myotis captured in mid-June were nonlactating; all nine female Myotis collected in late June were lactating. During early-mid-July, 82.6% (19 of 23) of the female Myotis were still lactating.

Activity

Wind seemed to be the major factor controlling nightly initiation of activity. On calm nights, bats were observed as early as 1930 h, about 15 to 20 min after sunset. At Hill Tank, activity appeared to peak between 2000 and 2030 h and ceased by 2100 h. During evenings when moderate-to-high winds persisted beyond 2100 h, no bats were seen or captured, although on several occasions bats were collected the following mornings. On one occasion (July 15) the wind subsided between 2000 and 2015 h, and bats were seen and captured by 2030 h.

All of the male Myotis were collected between 2030 and 2110 h, whereas 44% of the females were captured between 2000 and 2100. The remaining 56% of the females were collected the following morning (i.e., later than 2100 h). This pattern was observed in both nonlactating and lactating females.

All female Antrozous except one were collected later than 2100 h, seemingly indicating that Antrozous either has a more distant roost site

or a later activity period than Myotis. The single male Antrozous also was collected later than 2200 h.

Discussion

Humphrey[4] concluded that the availability and diversity of suitable roost sites, particularly nursery roosts, are the primary factors controlling the diversity of bats in an area. In this regard, the Los Medanos study area appears to be relatively sterile. The only major roost site in the area may be Livingston Ridge, located about 8 km west of Hill Tank. There appeared to be no other suitable roost sites in the study area, with the possible exception of an old building on the northeastern end of the site. The building was checked several times but no bats were found.

The low bat diversity in the study area is not surprising considering that most of the site lacks ridges, rock outcrops, or other roost sites. It is surprising, however, that Tadarida brasiliensis was not captured because the range of this bat has been documented to within 40 km of the study area along with Antrozous pallidus.[1] Coupled with this is the fact that Tadarida may roost with Antrozous.[3] Therefore, it seems possible that Tadarida occurs in small numbers in the study area, but was not collected during this study.

Summary

On 17 nights between May 23 and July 15, 1978, mist nets were set at cattle tanks on or near the Los Medanos WIPP site in Eddy Country, New Mexico. Fifty-eight bats representing two species of vespertilionids (M. velifer and A. pallidus) were captured. Both species were expected to occur in the area as known ranges extend to within 40 km of the site. We also expected a third species, T. brasiliensis, but we did not record it.

The low chiroptofaunal diversity can be explained as a function of the low availability and diversity of suitable roost sites.

Acknowledgments

We thank Troy L. Best and Donna C. Cole for their help and suggestions.

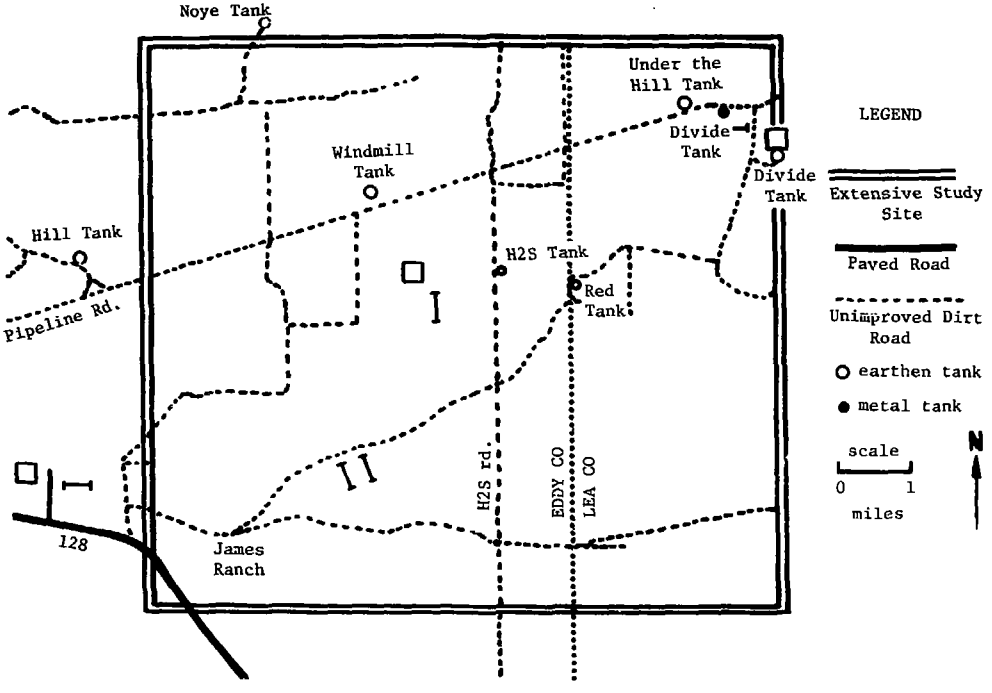

Figure 11.1. Map of the Los Medaños Study Area Showing Tank Locations

Table 11.1. Netting Dates and Locations at the Los Medaños WIPP Site (1978)

Date	Location	Nets Removed
23 May	windmill tank	2200 hours
24 May	divide tank (earthen	"
25 May	---[a]	---
26 May	H2S tank	2200 hours
13 June	hill tank	following morning
13 June	red tank	"
14 June	divide tank (earthen)	"
15 June	red tank	2200 hours
16 June	hill tank	following morning
27 June	hill tank	"
28 June	hill tank	"
29 June	---[a]	---
30 June	hill tank	following morning
8 July	hill tank	"
9 July	hill tank	"
10 July	hill tank	"
11 July	hill tank	"
13 July	red tank	"
14 July	under the hill tank	2200 hours
15 July	hill tank	following morning

[a]No nets set due to poor weather.

Table 11.2. Specimens of Bats Collected at the Los Medaños WIPP Site (1978)

Species	Sex	Date	Location	Museum Number[a]
Myotis velifer	M	8 July	Hill Tank	MSB37524
"	M	10 July	Hill Tank	MSB37525
"	M	10 July	Hill Tank	MSB37527
"	F	14 June	Hill Tank	MSB37516
"	F	28 June	Hill Tank	MSB37519
"	F	28 June	Hill Tank	MSB37520
"	F	29 June	Hill Tank	MSB37521
"	F	28 June	Hill Tank	MSB37522
"	F	8 July	Hill Tank	MSB37523
"	F	11 July	Hill Tank	MSB37526
Antrozous pallidus	M	10 July	Hill Tank	MSB37532
"	F	14 June	Hill Tank	MSB37517
"	F	17 June	Hill Tank	MSB37518
"	F	29 June	Hill Tank	MSB37528
"	F	29 June	Hill Tank	MSB37529
"	F	9 July	Hill Tank	MSB37530
"	F	10 July	Hill Tank	MSB37531

[a]Museum of Southwestern Biology, University of New Mexico

Table 11.3. Netting Results at the Los Medaños WIPP Site (1978). Numbers in parentheses indicate animals which escaped prior to sex determination. "Unknown" refers to bats which either escaped from the nets before they could be identified, or were partially eaten by mud turtles and could not be identified.

Date	*Myotis velifer* male	*Myotis velifer* female	*Antrozous pallidus* male	*Antrozous pallidus* female	Unknown
23 May	---	---	---	---	---
25 May	---	---	---	---	---
26 May	---	---	---	---	---
13 June	---	2[a]	---	1[b]	1[c]
14 June	---	---	---	---	---
15 June	---	---	---	---	---
16 June	---	---	--- (1)	1	2
27 June	---	3	---	---	---
28 June	---	5	---	2	1
30 June	---	1	---	---	---
8 July	2 (1)	14	---	2	---
9 July	--- (1)	2	---	1	---
10 July	1 (1)	5	---	1	1
11 July	---	2	---	---	---
13 July	---	---	---	---	---
14 July	---	---	---	---	---
15 July	1	---	1	1	1
Total:	4 (3)	34	1 (1)	9	6
	41		11		

[a]One bat caught at Hill Tank, the other at Red Tank.

[b]Caught at Hill Tank.

[c]Caught at Red Tank.

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CHAPTER 12

AQUATIC ECOSYSTEMS OF THE LOWER PECOS DRAINAGE, EDDY COUNTY, NEW MEXICO

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Introduction

A limnological study of selected water bodies on the down-slope from the WIPP site was inaugurated in late 1978. In addition, one playa site (Fig. 12.1, Station 1) was selected, which is up-slope to the WIPP site. These study stations are shown in Figure 12.1.

Station 10, labeled "Malaga Bend," is actually located at Pierce Canyon. Water samples were taken here to assess the effects of salt water influx at Malaga Bend, the strong river bend just upstream. Station 4 is located at the north end of Laguna Grande de la Sal near the point of a large artesian inflow of brine. This is probably the "Surprise Spring" of earlier reports[1] which is stated to have a discharge of from 435-472 dm^3 (115-125 gal) per minute. Just north of Surprise Spring is a small fresh-water spring, Station 5, named "Pupfish Spring," which has an estimated flow of < 20 dm^3/min.

The ground and surface water quality of Eddy County has been investigated extensively, primarily from the standpoint of chemical parameters.[1-5] The principal drainage is the Pecos River with perennial tributaries from the west only. East of the river, normally dry arroyos carry flood waters to the Pecos River or into closed basins. A significant topographic feature north and west of the WIPP site is Nash Draw, a subsidence-drainage basin at the lower end of which is the Laguna Grande de la Sal. Nash Draw is underlaid by the Rustler Formation which contains

several water-bearing zones, the basal one of which is in contact with the underlying Salado Formation and contains a saturated sodium chloride brine. This brine moves southwest in Nash Draw, past Laguna Grande de la Sal, to discharge into the Pecos River at Malaga Bend.[2] According to the report, "New Mexico Water Resources Assessment for Planning" (U.S. Department of the Interior 1976), the following amounts of total dissolved solids have been reported for the period 1956-65:[6]

Station	Average Total Dissolved Solids kg/year	mg/l
Pecos River at Carlsbad	1.289×10^8	2,384
Pecos River near Malaga	3.039×10^8	4,013
Pecos River at Pierce Canyon	4.591×10^8	5,891
Pecos River at Red Bluff	5.318×10^8	6,502

Robinson and Lang[1] have presented evidence to show that Laguna Grande de la Sal is a down-slope catchment basin for limited surface drainage and artesian saline aquifers. The saline inflow which adds an estimated 3.4×10^5 kg (340 tons) of salt per day to the Pecos at Malaga Bend is derived from a basal Rustler Formation aquifer which drains down-slope from Nash Draw under Laguna Grande de la Sal. The alluvium between Laguna Grande de la Sal and Malaga Bend has had several test wells drilled with lower chloride content than that of the lake proper. Depth-to-water measurements indicate that shallow water moves toward the lake in the alluvium just south of the lake. The following from Robinson and Lang is still a definitive statement of the complex hydrological problem:[1]

> "Three test wells were drilled in the vicinity of the lake--23-29-17VI (U.S.G.S. No. 4 test), 23-29-22CL (U.S.P.C. No. 1 test), and 23-29-28B6 (U.S.P.C. No. 2 test). In each of these wells, water of a different type and of a decidely [sic] lower chloride content than that of the lake brine was encountered below the bottom of the lake, indicating that the lake brine is probably not penetrating down to the brine horizon at the bottom of the Rustler Formation. Moreover, in none of the wells located between the lake and the Malaga Bend

which draw water from above this brine horizon was brine found with a concentration comparable to that of the brine in wells in the Malaga Bend. It appears improbable, therefore, that the lake brine is reaching Malaga Bend through permeable beds above the brine horizon."

Biological studies in the lower Pecos Valley of New Mexico have been few, chiefly isolated reports of aquatic animal and plant taxa. The fish fauna has been previously studied at limited stations on the Pecos, in the Red Bluff Reservoir,[7] and in the Black River drainage.[8] A three-year study of the Chironomidae, a component of the benthos, in relation to water quality has been conducted at one of the study sites.[9]

Materials and Methods

Water Quality

Water quality parameters were determined by following procedures outlined by the Hach Chemical Company[10] and Standard Methods.[11] Dissolved oxygen samples were collected in 300 ml BOD bottles and fixed in the field. An additional water sample (500-1000 ml) was obtained simultaneously for other analyses. Phosphate, nitrate, nitrite, and dissolved oxygen determinations were made within 6 h of sample collection. The unused portions of the samples were packed on ice and returned to the laboratory for analysis of pH, total hardness, chlorides, specific conductance, sulfates, and turbidity. Water samples for trace metal analysis were collected and fixed with nitric acid and shipped to Dr. LaVere Merritt, Brigham Young University, for examination.

Current velocity was measured with a pygmy-type water current meter (Weathermeasure Corp.). The audible blips were counted for two separate 15-s intervals and averaged. At the point of velocity measurement, width and depth of the stream were measured. The recording for velocity was

substituted in the calibration equation supplied by the manufacturer to obtain true current velocity.

Stage height benchmarks were established at 10 Mile Dam (Station 7), Harroun Crossing (Station 9), Pipeline Crossing (Station 11), and Upper Red Bluff Reservoir (Station 12). Six-ft sections of concrete rebar were driven into the stream substrate at all stations except Harroun Crossing, and a measurement was taken there from the top of the post to the water surface. The bridge at Harroun Crossing was selected as a benchmark with a measurement taken from the underside of the water surface. These stage heights will be integrated with those obtained at the Malaga Bend USGS station.

Net Plankton

Ten to 30 l of water from the middle of the water body at each station were strained through a Wisconsin style plankton net (fine mesh, 80 μ, nitex). The plankton concentrate was shipped on ice to Dr. Richard Baumann, Brigham Young University. A replicate preserved in 10% formalin was taken. Results were initially reported as counts per liter for major taxa only.

Nannoplankton

Nannoplankton, which was obtained by collecting the last liter of filtrate from the plankton net, was shipped on ice to Dr. Samuel Rushforth, Brigham Young University. Results were reported as number-per-liter. Phytoplankton productivity was determined as a separate subproject by Dr. Douglas Caldwell, University of New Mexico, and is presented in Chapter 7 of this report.

Aufwuchs

The aufwuchs assemblage (periphyton, epipelon, and epilithon) was sampled using a random composite method. Various substrata, such as leaves, small sticks, stones, etc, were collected at random and scraped with a knife; the collected material was composited in a container together with strands of filamentous algae, samples from mat algae, twigs,

small stones, etc. The container was placed on ice in a small styrofoam chest and shipped to Dr. Samuel Rushforth for examination. Results were reported as species composition and relative abundance.

Benthos

Both qualitative and quantitative assessments of benthos were made. Qualitative dip net samples were placed in plastic bags. The bags were placed on ice and were returned to the lab for rearing. Quantitative samples were taken with a modified Surber sampler[12] or a standard 6-in Ekman dredge. Site selection for Surber samples was made according to a procedure developed by Dr. Robert Winget, Brigham Young University. His approach, which is essentially a stratified random method,[13] is as follows:

> "One way to reduce variance between samples is to eliminate as many environmental variances as possible, such as water depth and velocity, substrate compositional variance, and vegetative cover. To utilize this concept, one set of environmental conditions is consciously selected at each sampling station. The preferred habitat in most streams is a clean riffle with large gravel-medium rubble and some sand-silt in the interstitial spaces between the rocks. This general stream habitat has more microhabitat types than any other stream habitat. In direct correlation to this, nearly all macroinvertebrate species found in a given stream are found in the riffle community; and generally in large enough numbers to provide a sound statistical base for sample data analysis."

A saturated salt solution was used to float the collected benthos. The liquid was decanted onto a #70 USGS brass screen with subsequent flotations made until no more additional organisms could be observed on the surface film or in the residues. All algae and/or other aquatic vegetation was retained. Initial preservation in the field was in 10% formalin. All Ekman samples were washed through a #70 screen. Preservation was the same as for Surber samples. All preserved benthic samples were washed with tap water in the lab and placed in 95% ethyl alcohol.

At least one entire sample from each station was hand sorted while the remaining samples were split into 8 subsamples using a turntable subsampler developed in Dr. Winget's laboratory. In preparation for subsampling, a sample was placed in a rectangular white pan and all large organisms (e.g., dragonfly and damselfly nymphs, large tabanids, etc) were removed. All large masses of vegetation were shredded into small pieces with forceps; then the sample was placed in the sample holder containing 8 to 10 marbles for agitation. The subsampler was run from 15 to 20 min or until no more of the residue could be washed from the sample container. Each of the 8 subsample chambers was washed onto a #70 screen and placed into 95% ethyl alcohol. Residue remaining in the sample container was treated likewise. All samples, subsamples, and residues were examined using a stereoscopic binocular microscope and the various taxa separated into vials of 95% ethyl alcohol.

As a test for homogeneity of subsampling, the chi-square test for differences in probabilities[14] was applied to two different Surber samples (cf. Appendix I, Samples A and B) in which all 8 subsamples were analyzed. The hypothesis tested in both cases was "all the probabilities in the same row are equal to each other". The alternative hypothesis was "at least two of them are different". Application of the first test (Appendix I, Series A) indicated that subsampling was valid at the 5% level for total numbers per subsample as well as total numbers per taxon. The second application (Appendix I, Series B) of the chi-square test for differences in probabilities indicated a source of error, either in total benthos per sample or among one or several taxa from the set of subsamples. Subsequent analysis was made with chi-square test for goodness of fit,[14] utilizing the total number of benthos per subsample. The hypothesis was "the distribution function of the observed random variable is the uniform distribution function":

$$F(X) = \begin{cases} 0 & X < 0 \\ X & 0 \leq X \quad 1 \\ 1 & 1 \leq X \end{cases}$$

The initial analysis included all taxa and the hypothesis was rejected at the 5% level ($p = 0.95$). Further analysis was made by subtracting the number of Oligochaeta from the total for each subsample. Oligochaeta are fragile and are known to fragment easily and were therefore suspected as the possible source of error. The null hypothesis was accepted under this arrangement. The error in numbers of oligochaetes was probably due to counting parts rather than individuals and may be directly attributed to fragmentation during initial sampling and/or subsampling.

Initial analysis of bottom samples consisted of sorting at least one sample from every date and locality in order to establish general trends. Other samples were analyzed as time permitted. For those dates and sample series where two or more samples were picked, step analysis was applied to determine the point at which a sufficient number of samples have been analyzed to provide data of desired statistical reliability.

In step analysis, successive samples are pooled and the standard error of the mean is compared to the mean for that pooled group. A reasonable error in most bottom fauna sampling is a standard error less than or equal to 20% of the mean. An equivalent approach is to use an index (D) or the ratio of the standard error to the arithmetic mean:[15]

$$D = \frac{\text{Standard error}}{\text{Arithmetic mean}} \times 100 \quad .$$

Sufficient samples have been analyzed when D stabilizes at or below 20 (cf. Appendix I, Series C).

Step analysis was also applied to several sets of subsamples with the criterion for reliability being changed to 5% of the mean. In most cases, two subsamples were sufficient to represent the total sample realistically.

Biomass determinations were made volumetrically using the technique of Ball.[16] These value relationships to dry weight appear to be adequate for larger or more numerous organisms but may be inadequate for smaller,

less abundant taxa. Consequently, dry weights will be determined from representative subsamples during the second year of study.

Ekman samples were taken at various sites along the spring flow (Pupfish Spring) at Laguna Grande de la Sal (Station 5). Clustered samples from the deepest water were taken at an upper and lower transect at Red Bluff Reservoir (Stations 12 and 13) and Hill Tank (Station 3).

Adult insects associated with aquatic habitats were sampled using a Malaise trap and by intensive sweep netting along stream or lake margins. The Townes' modification of the Malaise trap was set in middle to late afternoon and the sample removed midmorning of the following day. Some collections utilized ethyl acetate as the killing agent with specimens being stored with chlorocresol crystals until the insects were separated in the laboratory. Other collections were taken and stored in 40% isopropyl alcohol.

Some insects from sweep nettings were initially killed with ethyl acetate and stored in chlorocresol while others were killed and preserved in 40% isopropyl alcohol. All Malaise or sweep net collections were stored in isopropyl alcohol and transferred to 95% ethyl alcohol when returned to the laboratory.

Aquatic Macrophytes

Qualitative samples were taken throughout the growing season to determine species composition and relative abundance. Voucher specimens were assembled and verified against known herbaria specimens.

Nekton - Invertebrate Component

This faunal assemblage dominated by Hemiptera, Coleoptera, and occasionally certain Diptera (Culicidae) was only sampled qualitatively with dip nets and fine-meshed seines. Results will be reported as percentage composition by station and date during the second year of the study. Adequate methods to quantify this ecological component are lacking.

Nekton - Fish Component

Collections were made using woven and monofilament experimental gill nets, each composed of 9.14 m (30 ft) panels with 12.7 mm (1/2-in.), 25.4 mm (1 in.), 50.8 mm (2 in.), and 76.2 mm (3 in.) meshes. The nets were tied at the bank, usually at the smallest mesh panel, and set running obliquely to the center of the river. Both nets were set on the same side of t e ver running parallel or each mirroring the other from opposite banks. Set times were from late afternoon to the following morning. All fish captured were weighed in the field to the nearest gram and measured for standard length and total length (mm). Shad [Dorosoma cepedianum eSueur)], when numerous in the catch, were visually separated into different length groups with one weight recorded for the entire group, and standard and total lengths recorded for several individuals randomly selected within the group.

Specimens retained were field-preserved in 10% formalin and transferred to 40% isopropyl alcohol in the laboratory after about one week of initial fixation. Very large specimens were injected with 10% formalin and retained in the initial preservative a longer time.

Sampling of riffles and shallow areas of pools was accomplished using a 4.6-m (15-ft), 3.2-mm (1/8-in.) mesh seine. Specimens collected were preserved as previously noted. Identification was made in the laboratory and the collection separated by species.

Biomass estimates for fish were made by replicated sections of the stream being blocked by fine-meshed seines and the section exhaustively seined until no further specimens were taken (Fig. 12.6). Live weights were recorded and the fish returned to undisturbed sections of the stream.

Results and Discussion

Water Quality

The Pecos River below Carlsbad is a stream of extremes in many parameters--some due to natural perturbations, others, man-made. The total flow at 10 Mile Dam (Station 7, Fig. 12.1) is dedicated to irrigation. During most of the year Harroun Canal (Station 8) diverts essentially all of the flow. The riverbed below 10 Mile Dam consists of a series of trickle riffles separating a series of long pools. Usually, many of the riffles dry up during the late summer so that the riverbed consists of a series of isolated stagnant pools. East of Malaga, the inflowing Black River, a perennial spring-fed stream of better water quality, augments the flow so that from this point to Red Bluff Reservoir the stream usually flows year around. At Malaga Bend a series of saline springs empty into the river resulting in one of the most severely limited, and at the same time, one of the most unusual streams in the United States. Just above Red Bluff Reservoir the Delaware River (Creek), a small perennial, spring-fed stream, empties into the Pecos. However, its small flow volume only slightly ameliorates the high salinity of the Pecos.

Figures 12.3 to 12.6 present the horizontal variation in selected parameters from the Laguna Grande de la Sal, Pupfish Spring, Pecos River, and Red Bluff Reservoir stations. The influx of saline water at Malaga Bend (above Station 10, Fig. 12.1) results in not only a significant elevation of sodium chloride (Figs. 12.2 A, B) but also elevated values of potassium (Fig. 12.3 C), mercury and nickel (Fig. 12.3 C), silver (Fig. 12.4 A), selenium, zinc, and lead (Fig. 12.4 B), and manganese, cadmium, and barium (Fig. 12.6 A).

Station 1, Playa Lake, did not fill during the study period. Consequently, no results are reported here. A series of dry soil samples from the playa basin was flooded in the laboratory. Organisms resulting did not differ from those reported by Sublette and Sublette.[17]

Station 2, Windmill Tank, was one of two aquatic sites studied on the WIPP site proper (the other was Hill Tank, Station 3). Water quality parameters are given in Appendix II. These parameters agreed with those previously reported from this well[5] (Table 6), except that chlorides have apparently increased in the time intervening since that sampling date (September 12, 1972).

Station 3, Hill Tank, showed some variation in water quality parameters, apparently dependent upon the degree of basin filling. During this study period, the pond had dried to wet mud on the first visit (no water sample taken) and was completely dry until June, at which time it had partially filled followed by more extensive filling in August and September (cf. Appendix II).

Station 4, Laguna Grande de la Sal, is a shallow (maximum depth 3 m) saturated brine salt lake. Human perturbations include waste water disposal from the United States Potash Refinery,[1] now discontinued, and present day mining operations. A small amount of the brine is being removed by tank truck for oil field water injection. The smaller salt lakes on New Mexico Highway 128, about two miles to the northeast, show clear evidence of long-term increased inundation (drowned salt cedars, inundated windmill, fence rows, etc). These water level relationships to Laguna Grande de la Sal are unclear at this time. At all dates sampled, except June 13, 1978, electrolytes were exceedingly high (Appendix II). The June sampling period was immediately following extensive rainfall in the area and it is presumed that a temporary layer of fresher water on the lake's surface was sampled at that date.

Station 5, Pupfish Spring, is a small flow spring (<20 dm^3/min) of lower salinity than Laguna Grande de la Sal (Appendix II). However, the water is still sufficiently saline so as to restrict all but a few groups of saline tolerant freshwater organisms.

Station 6, Pecos River below 6 Mile Dam, was not sampled for physicochemical parameters but is presumed to be similar to Stations 7 and 8 (below).

Station 7, the Pecos River below 10 Mile Dam, and Station 8, Harroun Crossing, exhibited similar water quality (Figs. 12.3 to 12.6; Appendix II). However, the flow at Station 7 was extremely limited during most of the year while that at Station 8 was a moderate flow and fairly uniform except during a spate. This greater uniformity at Station 8 is attributed to the inflow of the Black River immediately above the station.

Stations 10 and 11, Malaga Bend (Pierce Canyon Crossing) and El Paso Natural Gas Co. Pipeline Crossing, also exhibited similar water quality characteristics (Figs. 12.3 to 12.6 and Appendix II). The significantly increased salinity is the result of basal zone Rustler Formation Springs at Malaga Bend.[1] This increased electrolyte concentration is still clearly evident at Stations 12 and 13, Upper and Lower Red Bluff Reservoir (Figs. 12.3 to 12.6 and Appendix II).

Long-term trends in specific conductance, chlorides, and sulfates at Station 13 are given in Figure 12.6 B. A seasonal pattern appears to be evident for the years 1972, 1974, and 1975 in which a reduced flow during July-August together with attendant high evaporation results in elevated electrolyte concentrations. The values for 1976 and 1977 have coincided with extremely low lake levels.

Aufwuchs (Periphyton)

The alga components of this biocoenosis have been examined by Dr. Samuel Rushforth, Brigham Young University. His most noteworthy results include the occurrence of marine littoral species as well as species found in inland saline waters elsewhere. Windmill Tank and Hill Tank have a flora characteristic of many lentic water bodies elsewhere in the Western United States.

Plankton (Phytoplankton)

Productivity for the phytoplankton component has been determined by Dr. Douglas Caldwell and is reported in Chapter 7. Species composition and relative abundance of phytoplankton have also been determined by Dr. Rushforth.

Plankton (Zooplankton)

No attempt has been made to date to determine species composition, and only general quantitative estimates are available. These have been prepared by Dr. Richard Baumann, Water Quality Laboratory, Brigham Young University.

Benthos

The macroscopic bottom-dwelling invertebrates of the aquatic biotopes studied exhibited a great diversity between stations and considerable seasonal change. The results presented here are suggested trends only, since statistical confirmation of sampling adequacy has not yet been obtained for all stations (cf. Appendix I). Table 12.1 presents a checklist of all benthic organisms identified to date.

Station 1, Playa Lake, was not filled during the period of field work; consequently, no samples were taken. The fauna of this type of water body has been previously studied for the nearby area by Sublette and Sublette.[17] Table 12.2 lists the organisms reported by them.

The benthos of Station 2 was not sampled because of the special nature of the habitat (concrete stock tank). However, faunal elements are known from other regional studies.[17] Table 12.3 lists the known organisms of windmill tanks for the area.

Station 3 benthos has been analyzed for two dates in January only. The macroscopic benthic fauna was dominated by two groups, the Chironomidae (midge larvae) and Ceratopogonidae (biting gnat larvae). Figure 12.7 A presents the changes in these two major benthic components. The time span between January 4 and 19 resulted in a significant faunal

shift due to drying up of the pond. It is evident that ceratopogonids can survive up to the point of drying of the sediments while the chironomids virtually disappear as the pond approaches dryness (cf. Appendix III).

Station 4 was examined qualitatively and does not appear to have a macroscopic benthic fauna. Occasional Ephydridae (shorefly) puparia were observed near the lake margin just below Pupfish Spring.

Station 5, Pupfish Spring, has a benthic fauna dominated by the Ceratopogonidae (Appendix III). Ephydridae appear to be seasonally abundant in the dredge samples. Due to the high salinity, this biotope is, at best, marginal for most fresh water organisms. Consequently, numbers of species present are greatly reduced when compared with a normal fresh water habitat (cf. Appendix III). Comparable reductions in number of species were also observed on the lower Pecos sites.

The Pecos River below 6 Mile Dam, Station 6, was added as a secondary collecting station. Consequently, only one date of collection is represented in the series. This station is a short distance below the Carlsbad sewage outfall into the Pecos. As a result biological productivity is high (Fig. 12.7 B; Appendix III). The benthic fauna at this station is dominated by a species of Simuliidae (black fly larvae) and several species of Chironomidae (midges). The simuliids are restricted to areas of moderate, steady stream flow with relatively high productivity of aufwuchs which produces the potamoplankton requisite to their feeding. The high aufwuchs productivity also serves as the nutrient base for the second most abundant group, the Chironomidae, most species (at this location) being aufwuchs "scrapers".

The Pecos River at 10 Mile Dam, Station 7, has such a reduced flow in the riffle areas that larger fish cannot enter. Consequently, the lack of fish "grazing" results in dense mats of green algae which support a high number and biomass of benthic organisms. There is a marked seasonal change in composition of dominant forms (Fig. 12.7 C; Appendix III), with amphipod crustaceans (scuds), chironomids, oligochaetes (earthworms), and snails being the most important groups. This stream station immediately

below 10 Mile Dam is little affected by the scouring action of spates. It is probably the most stable of the stations examined.

Station 8, Harroun Canal, was sampled at one date only. A limited fauna was observed (Appendix III), undoubtedly due to the lack of substratum variability.

The Pecos River at Harroun Crossing, Station 9, is the most "normal" stream station on the Pecos below Carlsbad. This is undoubtedly due to the ameliorating effects of the Black River which empties into the virtually dewatered Pecos just above this station. Being spring-fed, Black River provides a steady flow of moderate (for this area) quality water. This was the only station where several groups of organisms occurred and one of them, the trichopteran Cheumatopsyche (caddisfly larva), constitutes one of the dominant forms, closely followed by Chironomidae and Oligochaeta. Biological productivity at this station is high. Figures 12.8 A-D (cf. also Appendix III) presents some of the seasonal changes in number and biomass of several significant faunal components.

Station 10, Pecos River below Malaga Bend at Pierce Canyon Crossing, is extremely degraded when compared to the immediate upstream station at Harroun Crossing. This abrupt change is undoubtedly due to the large natural inflow of saline water at Malaga Bend.[1] The Nematoda, the major group, are of a size range to be conaidered meiofauna rather than macroscopic benthic fauna [cf. Appendix III for the relative abundance (numerical) of other groups].

Station 11, Pecos River at the El Paso Natural Gas Co. Pipeline Crossing, presents essentially the same features as Station 10. Of unusual interest is the presence of Foraminifera, a group of macroscopic shelled Protozoa normally found in estuarine or marine habitats. The presence of the group here may be through an introduction from the Texas Gulf Coast in company with an (unsuccessful) introduction of three marine species of fish made into Red Bluff Reservoir by the Texas Parks and

Wildlife Department. The relative abundance (numerical) of the major groups is given in Appendix III.

Stations 12 and 13, Upper and Lower Red Bluff Reservoir, exhibit many of the faunal features of the Pecos River at Station 11 (cf. Appendix III). The high salinities of the reservoir, as the lower stretches of the stream below Malaga Bend, can support only a depauperate fauna of those highly saline tolerant species. The horizontal (by station) and seasonal distribution of two of the most saline-tolerant groups, the Oligochaeta and Nematoda, is shown in Figs. 12.9 A, B.

Nekton (Invertebrate)

Components of this assemblage have been sampled qualitatively. Techniques for adequate quantification are lacking. Mark and recapture methods are applicable but are prohibitively expensive. Identifications of these groups are underway and will be reported at a later date. One species of unusual interest from this assemblage has been identified from Red Bluff Reservoir, Palaemonetes (Palaemonetes) pugio Holthius. This shrimp, a brackish water species previously known from the Texas Gulf Coast, may have been introduced along with the estuarine fish introduced into Red Bluff Reservoir.

Nekton (Vertebrate)

The fish component has been sampled both qualitatively and semi-quantitatively at all stations where they occur. Table 12.4 presents a checklist by station. Table 12.5 lists species composition and relative abundance, all dates of collection combined. One biomass estimate was made on two adjacent sections of the Pecos River at Harroun Crossing (Fig. 12.2). The results of this sampling endeavor are presented in Table 12.6.

Of the ichthyofauna, four species are on the State of New Mexico Endangered Species list. These are: Pecos River Pupfish (Cyprinodon pecosensis), rainwater fish (Lucania parva), gray redhorse (Moxostoma congestum) and blue sucker (Cycleptus elongatus). Our studies indicate several thriving populations of the first two species. Consequently, a

recommendation is being made to the New Mexico Department of Game and Fish, Endangered Species Program, to "delist" these two species. The populations of Moxostoma congestum are much more limited. However, a moderate population exists in the Black River Drainage as do those of an additional five species of endangered fish: blue sucker (Cycleptus elongatus), banded tetra (Astyanax mexicanus), blunt nose minnow (Dionda episcopa), green-throated darter (Etheostoma lepidum), and Pecos gambusia (Gambusia nobilis). The latter two species are found only in the Blue Spring run.

Aquatic herptiles have been sampled qualitatively only. Quantitative methods, as for nektonic invertebrates, would entail prohibitively expensive mark and recapture techniques. Table 12.7 lists the herptiles taken to date.

Aquatic Macrophytes

This biotic assemblage, including wetland species, has been sampled qualitatively only. Table 12.8 lists the species collected by station. Additional species may be encountered during subsequent years. To assess the potential occurrence at the study sites, a checklist has been prepared for Eddy and Lea Counties, New Mexico, and adjacent areas of the Trans-Pecos Texas.

Summary

1. Preliminary physicochemical and biological features of 12 aquatic stations in Eddy Co., New Mexico, and Reeves County, Texas, have been described from winter, spring, and summer samples.

2. Natural inflow of saline water results in unusual algae assemblages at several sites.

3. Benthic invertebrates also reflect the distribution of saline water at the various study stations. Unusual saline water components include Foraminifera, an estuarine oligochaete, and a palaemonid shrimp.

4. Station 9, Pecos River at Harroun Crossing, just below the mouth of the Black River, more closely resembles through its faunal components hard water stream assemblages in other areas of the United States.

5. Stations 10 to 13, Pecos River and Red Bluff Reservoir are unique among rivers and reservoirs reported heretofore in the American literature, in terms of their unusual saline tolerant/marine species components.

6. The fish and herptile fauna of the permanent water stations is restricted both in number of species and numbers of individuals. A total of 19 species of fish occurred in the general study area. Of these, four species, C. pecosensis, M. congestum, L. parva, and C. elongatus, are on the State of New Mexico Endangered Species list. An additional four species, A. mexicanus, D. episcopa, E. lepidum, and C. nobilis which occur in the Black River drainage, are also on the State of New Mexico Endangered Species list. The last named species is also on the federal list.

7. An extensive aquatic flora exists in Eddy and Lea Counties but relatively few of these tolerate the excessive salinities of the lower Pecos River and Red Bluff Reservoir in New Mexico. To date, 20 species have been found at the study stations.

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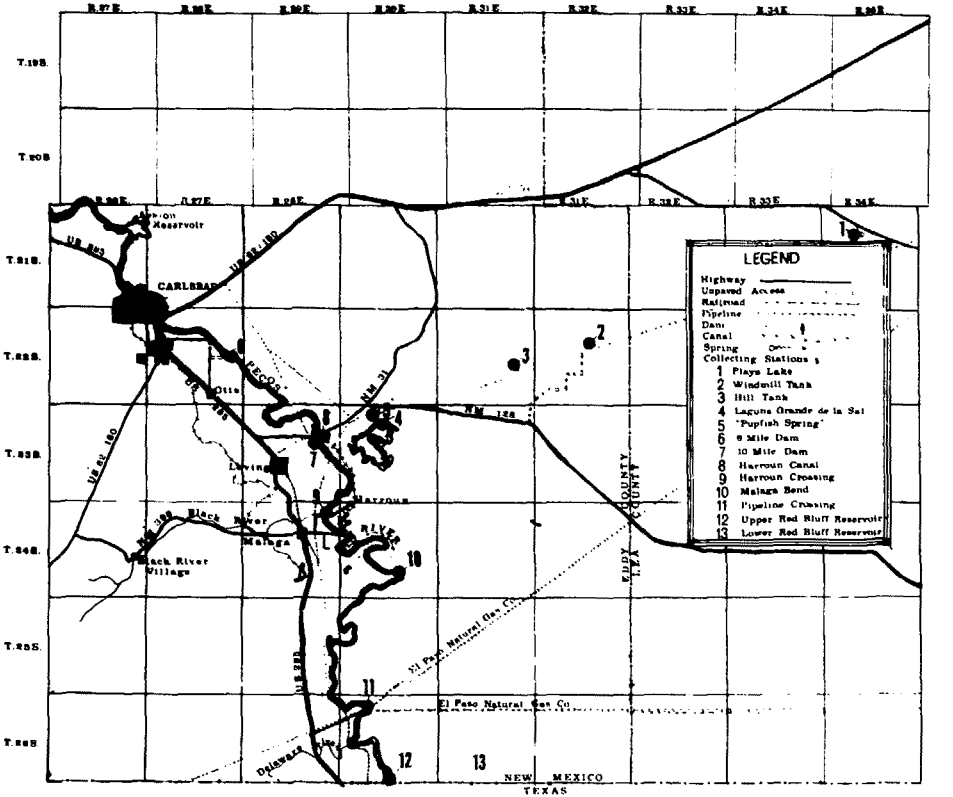


Fig. 12.1. Aquatic ecosystems study stations, 1977-78.

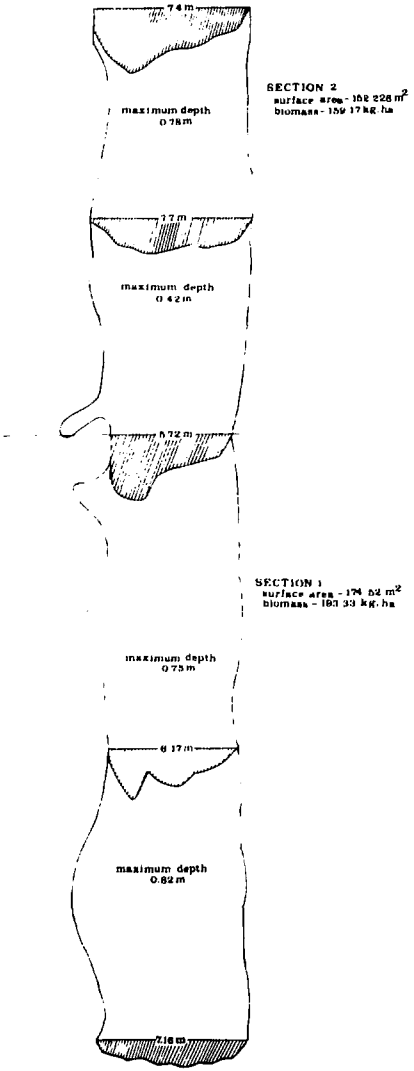


Fig. 12.2. Replicated sections at Station 9, Harroun Crossing, used for fish biomass estimates.

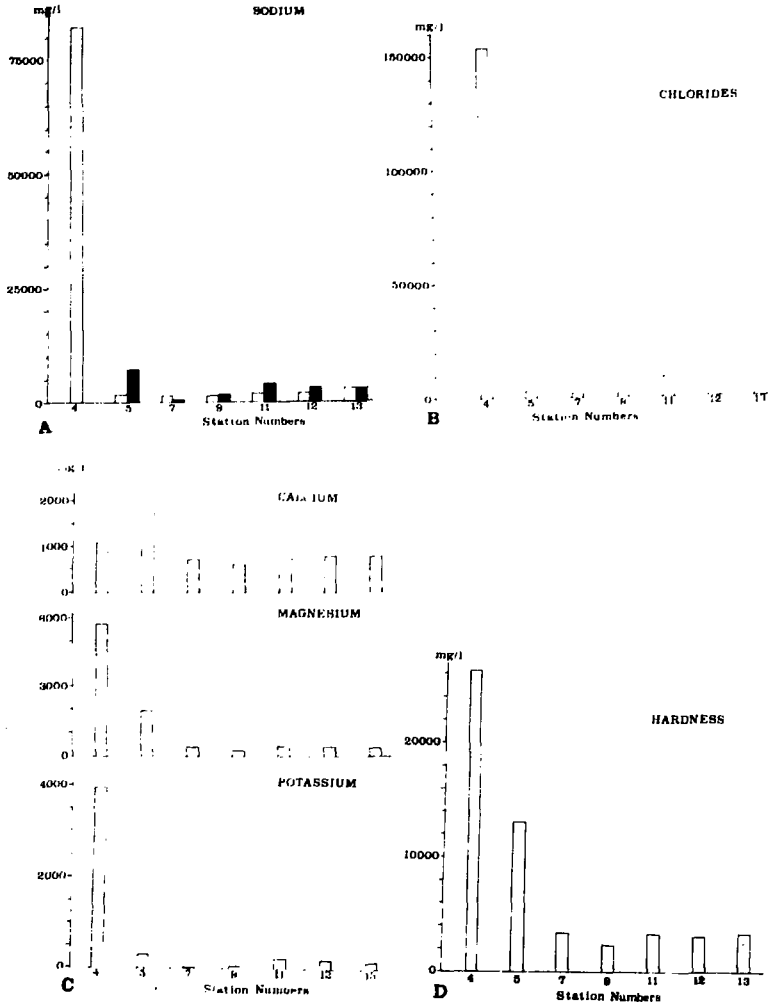


Fig. 12.3. A) Horizontal distribution of Sodium (as Na), winter series. Symbols: open, January; solid, February. B) Horizontal distribution of Chlorides (as Cl). C) Horizontal distribution of Calcium (as Ca), Magnesium (as Mg), and Potassium (as K), winter series. D) Horizontal distribution of (total) hardness (as $CaCO_3$), winter series. See Fig. 12.1 for station locations.

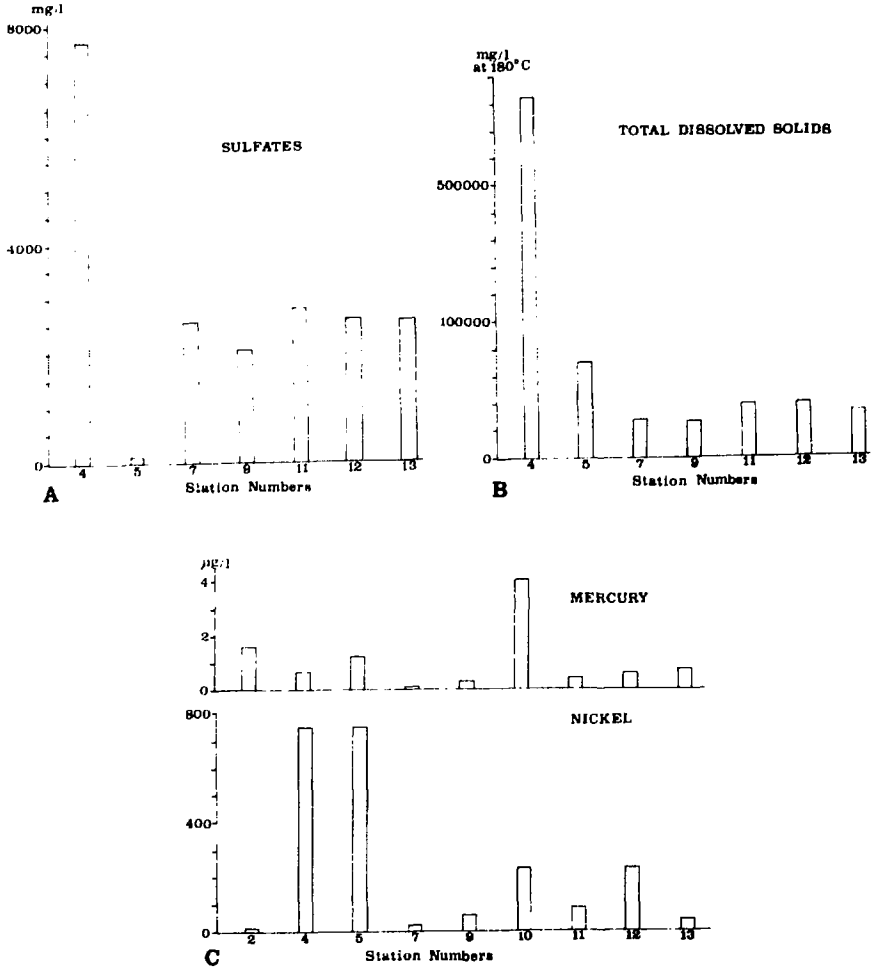


Fig. 12.4. A) Horizontal distribution of Sulfates (as SO_4), winter series.
B) Horizontal distribution of Total Dissolved Solids, winter series.
C) Horizontal distribution of Mercury (as Hg) and Nickel (as Ni), winter series. See Fig. 12.1 for station locations.

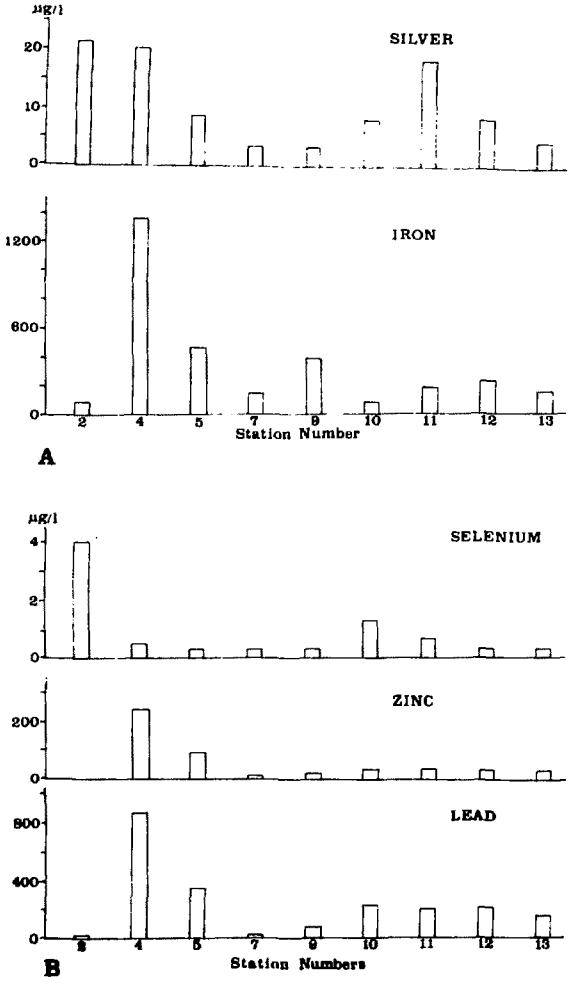
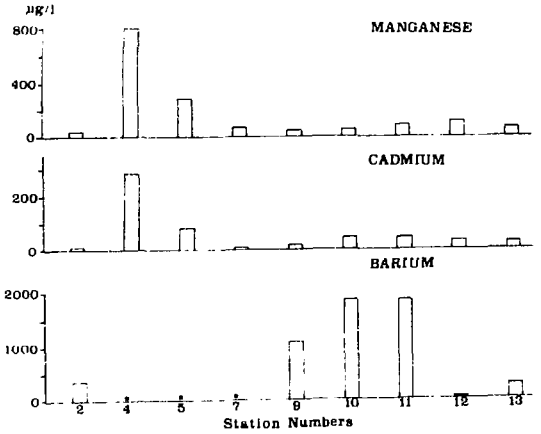
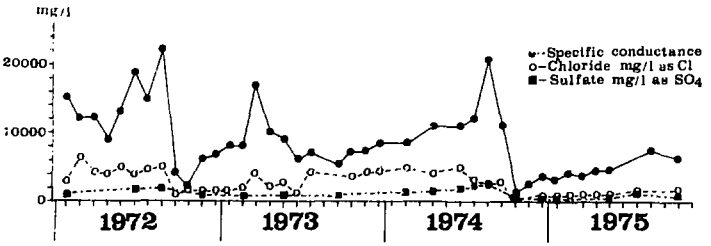
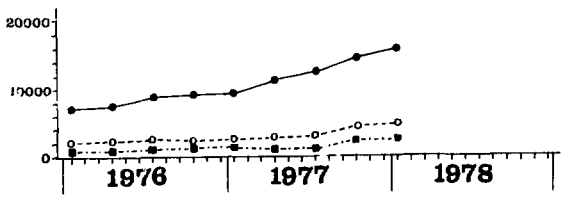


Fig. 12.5. A) Horizontal distribution of Silver (as Ag) and Iron (as Fe), winter series. B) Horizontal distribution of Selenium (as Se), Zinc (as Zn) and Lead (as Pb), winter series. See Fig. 12.1 for station locations.



A





B

Fig. 12.6. A) Horizontal distribution of Manganese as (Mn), Cadmium (as Cd) and Barium (as Ba), winter series. Asterisk indicates salinity was too high for a reading to be taken. See Fig. 12.1 for station locations. B) Long term trends in Specific Conductance (µmhos/cm^2), Chlorides, and Sulfates at Station 13, Lower Red Bluff Reservoir (data courtesy Texas Water Quality Board).

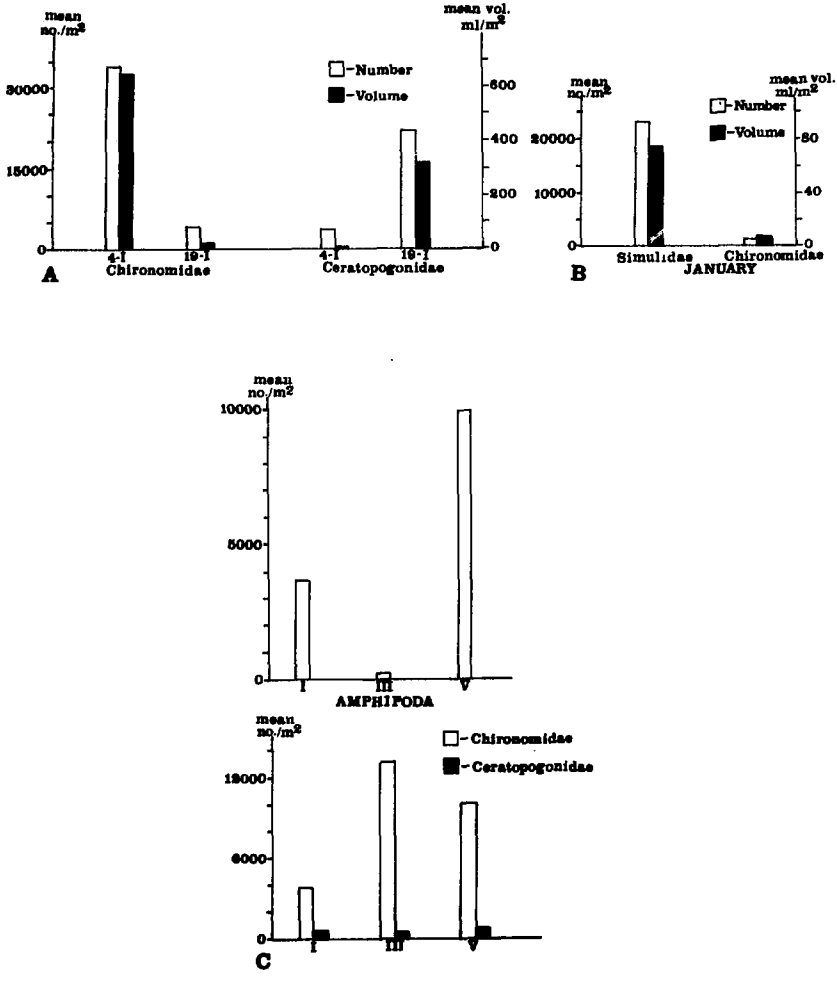


Fig. 12.7. A) Changes in number and biomass (volume) of two of the major benthic components of Hill Tank, Station 3, as the pond approaches dryness. B) Number and biomass (volume) of the two major benthic groups at Station 6, Pecos River below 6 Mile Dam. C) Seasonal changes in number and biomass (volume) of three groups of benthic organisms at Station 7, Pecos River below 10 Mile Dam.

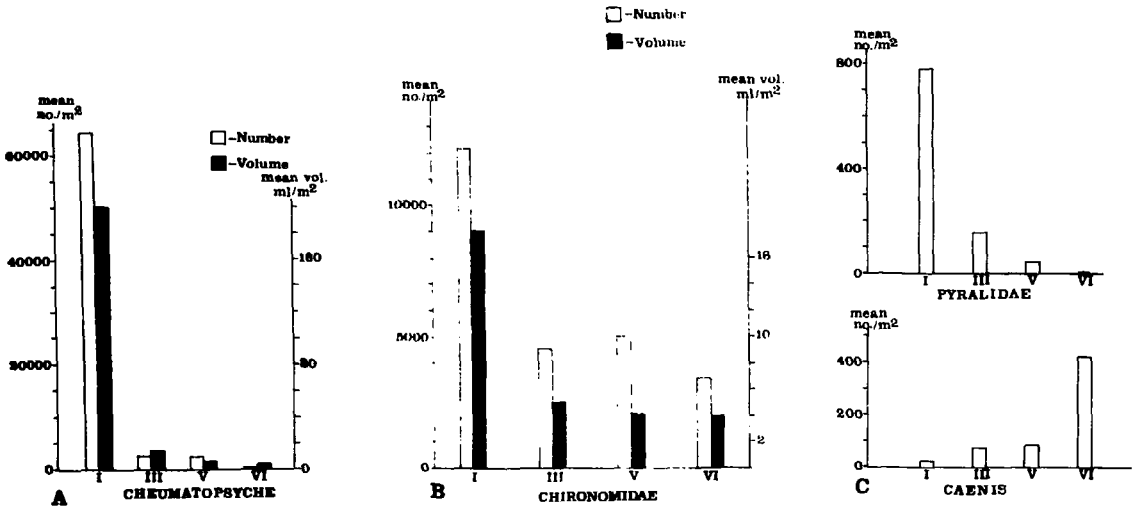
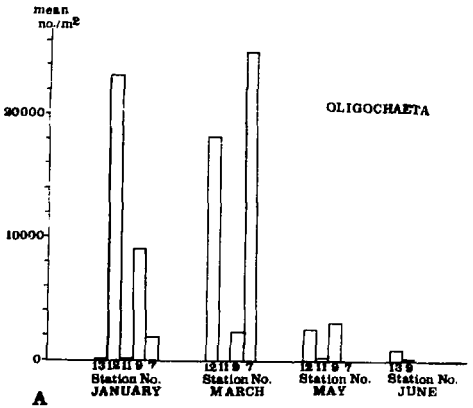


Fig. 12.8. A) Seasonal changes in number and biomass for Cheumatopsyche (Trichoptera) at Station 9, Harroun Crossing. B) Seasonal changes in number and biomass for Chironomidae (Diptera) at Station 9, Harroun Crossing. C) Seasonal changes in number for Pyralidae (Lepidoptera) and Caenis (Ephemeroptera) at Station 9, Harroun Crossing.



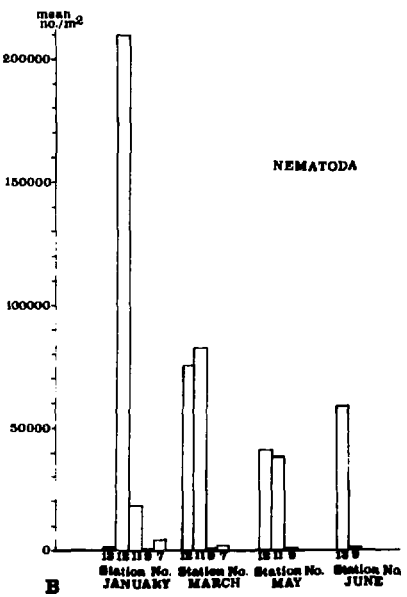


Fig. 12.9. A) Spatial and temporal distribution (numerical) of the Oligochaeta and B) Nematoda. See Fig. 12.1 for station locations.

Table 12.1. Checklist of Benthic Organisms by Station

STATION 2, WINDMILL TANK
Insecta
  Diptera
    Chironomidae (midges)
      Chironomus decorus group
      Chironomus stigmaterus Say

STATION 3, HILL TANK
Oligochaeta (earthworms)
  Dero new species

Crustacea
  Amphipoda (scuds)
    Hyalella azteca (de Saussure)

Insecta
  Hemiptera (true bugs)
    Corixidae (water boatmen)
  Diptera (true flies)
    Ceratopogonidae (biting gnats)
    Chironomidae (midges)
      Chironomus decorus group
  Dolichopodidae (long-legged flies)

Acari

Mollusca
  Sphaerium species (fingernail clams)

STATION 5, PUPFISH SPRING
Nematoda

Oligochaeta (earthworms)
  Paranais litoralis (Müller)

Crustacea
  Amphipoda (scuds)
    Hyallella azteca (de Saussure)

Insecta
  Diptera (true flies)
    Ceratopogonidae (biting gnats)
    Chironomidae (midges)
      Chironomus stigmaterus Say
    Dolichopodidae (long-legged flies)
    Ephydridae (shore flies)
      Ephydra cinerea Jones
      Ephydra packardi Wirth
    Stratiomyidae (soldier flies)

STATION 6, PECOS RIVER AT 6 MILE DAM
Nematoda

Oligochaeta (earthworms)
  Limnodrilus hoffmeisteri Claparede
  Potamothrix bavaricus (Öschmann)

Crustacea
  Amphipoda (scuds)
    Hyallella azteca (de Saussure)

STATION 6 CONTINUED
Insecta
  Collembola (springtails)
  Odonata
    Anisoptera (dragonflies)
    Zypoptera (damselflies)
      Argia moesta (Hagen)
      Ischnura barberi (Currie)
      Ischnura demorsa (Hagen)
  Coleoptera
    Hydrophilidae (water scavenger beetles)
  Diptera
    Ceratopogonidae (biting gnats)
    Chironomidae (midges)
      Chironomus decorus Joh.
      Chironomus stigmaterus Say
      Cricotopus bicinctus (Mg.)
      Cricotopus sylvestris (Fabr.)
      Cricotopus new species 1
      Microspectra nigripila (Joh.)
      Parachironomus monochromus (Van der Wulp)
      Tanypus neopunctipennis Sublette
      Tanytarsus new species 1
    Dolichopodidae (long-legged flies)
    Muscidae (house-flies)
    Psychodidae (moth flies)
    Simuliidae (black flies)
    Tabanidae (horse flies)

Acari

Mollusca
  Physa virgata Gould (snail)

STATION 7, PECOS RIVER AT 10 MILE DAM
Nematoda

Oligochaeta (earthworms)
  Limnodrilus hoffmeisteri Claparede
  Monopylephorus new species
  Paranais litoralis (Müller)
  Potamothrix bavaricus (Öschmann)

Hirudinea

Crustacea
  Amphipoda (scuds)
    Hyallella azteca (de Saussure)

Insecta
  Ephemeroptera (mayflies)
    Caenis simulans McD.
  Odonata
    Anisoptera (dragonflies)
    Zygoptera (damselflies)
      Argia immunda (Hagen)
      Argia moesta (Hagen)
      Argia nahuana Calvert
      Ischnura barberi (Currie)
      Ischnura denticollis (Burmeister)

Table 12.1, continued

STATION 7 CONTINUED
Coleoptera
Dytiscidae (predaceous diving beetles)
Laccophilus proximus Say
Hydrophilidae (water scavenger beetles)
Enochrus hamiltoni (Horn)
Enochrus pygmaeus (Fabricius)
Diptera
Ceratopogonidae (biting gnats)
Chironomidae (midges)
Cricotopus bicinctus (Mg.)
Cricotopus infuscatus (Malloch)
Dicrotendipes californicus (Joh.)
Pseudochironomus pseudoviridis (Malloch)
Dolichopodidae (long-legged flies)
Ephydridae (shore flies)
Ephydra packardi Wirth
Parascatella triseta (Coq.)
Scatella paludum (Meigen)
Muscidae (house-flies
Psychodidae (moth flies)
Simuliidae (black flies)
Stratiomyidae (soldier flies)
Tabanidae (horse flies)

Mollusca
Physa virgata Gould (snail)

STATION 8, HARROUN CANAL
Nematoda

Oligochaeta (earthworms)
Dero obtusa d'Udekem
Aulodrilus pigueti Kowalewski

Insecta
Diptera (true flies)
Chironomidae (midges)

STATION 9, PECOS RIVER AT HARROUN CROSSING
Nematoda

Oligochaeta (earthworms)
Limnodrilus udekemianus Claparede
Monopylephorus species 1
Paranais frici Hrabe
Paranais litoralis (Müller)
Potamothrix bavaricus (Öschmann)

Hirudinea (leeches)

Crustacea
Amphipoda (scuds)
Hyallella azteca (de Saussure)

Insecta
Collembola (springtails)
Ephemeroptera (mayflies)
Caenis simulans McD.

STATION 9 CONTINUED
Odonata
Anisoptera (dragonflies)
Zygoptera (damselflies)
Argia alberta Kennedy
Argia moesta (Hagen)
Ischnura barberi (Currie)
Hetaerina americana (Fabr.)
Coeloptera
Dryopidae (crawling water beetles)
Hexacylloepus ferrugineus? (Horn)
Microcylloepus pusillus LeConte
Stenelmis bicarinata?
Hydrophilidae (water scavenger beetles)
Berosus species
Trichoptera (caddisflies)
Cheumatopsyche campyla Ross
Itchytrichia prob. clavata Morton
Hydroptila angusta Ross
Hydropsyche species
Lepidoptera
Pyralidae (aquatic moths)
Paragyractis kearfottalis (Dyar)
Diptera
Ceratopogonidae (biting gnats)
Chironomidae (midges)
Cladotanytarsus (Lenziella) cruscula (Saether)
Cricotopus bicinctus (Mg.)
Cricotopus infuscatus (Malloch)
Dicrotendipes californicus (Joh.)
Orthocladius new species 1
Parakiefferiella new species 1
Pentaneura inconspicua (Malloch)
Pseudochironomus pseudoviridis (Malloch)
Rheotanytarsus exiguus (Joh.)
Telopelopia okoboji (Walley)
Simuliidae (black flies)
Tabanidae (horse flies)

Acari

Mollusca
Physa virgata Gould (snail)

STATION 10, PECOS RIVER AT MALAGA BEND (PIERCE CANYON)
Nematoda

Oligochaeta (earthworms)
Paranais litoralis (Müller)

Insecta
Odonata
Zygoptera (damselflies)
Argia moesta (Hagen)
Ischnura barberi (Currie)
Diptera
Chironomidae (midges)

Table 12.1, continued

STATION 11, PECOS RIVER AT EL PASO NATURAL GAS PIPELINE CROSSING

Foramenifera

Nematoda

Oligochaeta (earthworms)

Insecta
- Odonata
  - Zygoptera (damselflies)
    - *Ischnura barberi* (Currie)
    - *Ischnura demorsa* (Hagen)
- Coleoptera
  - Hydrophilidae (water scavenger beetles)
- Diptera
  - Ceratopogonidae (biting gnats)
  - Chironomidae (midges)
    - *Tanytarsus* (*Lenziella*) *cruscula* (Saether)

Mollusca
- *Physa virgata* Gould (snail)

STATION 12, UPPER RED BLUFF RESERVOIR

Nematoda

Oligochaeta (earthworms)
- *Limnodrilus udekemianus* Claparede
- *Paranais frici* Hrabe
- *Paranais litoralis* (Müller)

Insecta
- Diptera
  - Ceratopogonidae (biting gnats)
  - Chironomidae (midges)
    - *Dicrotendipes californicus* (Joh.)
    - *Polypedilum digitifer* Townes
    - *Pseudochironomus pseudoviridis* (Malloch)
    - *Tanypus neopunctipennis* Sublette
  - Culicidae (mosquitoes)
    - *Culiseta inornata* (Will.)

STATION 13, LOWER RED BLUFF RESERVOIR

Nematoda

Oligochaeta
- *Paranais frici* Hrabe

Crustacea
- Amphipoda (scuds)
  - *Hyalella azteca* (de Saussure)

Insecta
- Diptera
  - Ceratopogonidae (biting gnats)
  - Chironomidae (midges)
  - Muscidae (house-flies)

Table 12.2. Playa Lake Fauna of Eastern New Mexico and Western Texas

Turbellaria (flat worms)
  Undetermined species

Oligochaeta (earthworms)
  Naididae
    Undetermined species

Hirudinea (leeches)
  Undetermined species

Mollusca
  Gastropoda (snails)
    Helisoma trivolvis Say
    Lymnaea bulimoides Lea

Crustacea
  Anostraca (fairy shrimp)
    Streptocephalus texanus (Packard)
    Streptocephalus dorothae Mackin
    Thamnocephalus platyurus Packard
    Branchinecta campestris Lynch
    Branchinella new species
  Notostraca (tadpole shrimps)
    Triops longicaudatus LeConte
  Conchostraca (clam shrimps)
    Leptestheria compleximanus (Packard)
    Lynceus brevifrons (Packard)
    Eocyzicus concavus (Mackin)
    Caenesteriella setosa (Pearse)
    Eulimnadia inflecta Mattox
    Cyzicus new species
  Ostrocoda (ostracods)
    Cypriconcha gnathostomata Ferguson

Insecta
  Odonata
    Anisoptera (dragonflies)
      Tarnetrum corruptum (Hagen)
      Pantala flavescens Fabricius
    Zygoptera (damselflies)
      Lestes alcer Hagen
  Ephemeroptera (mayflies)
    Cloeon species
  Hemiptera (true bugs)
    Corixidae (water boatman)
      Corisella tarsalis (Fieber)
      Corisella edulis (Champion)
      Sigara (Vermicorixa) species near modesta (Abbott)
      Ramphocorixa acuminata (Uhler)
    Belostomatidae (giant water bugs)
      Undetermined species
    Notonectidae (back swimmers)
      Notonecta undulata Say
      Notonecta species
    Coleoptera
      Dytiscidae (predaceous diving beetles)
        Copelatus glyphicus (Say)
        Thermonectes nigrofasciatus ornaticollis Aube
        Laccophilus fasciatus terminalis Sharp
        Hygrotus nubilus (LeConte)

Dytiscidae continued
        Eretes sticticus (Linnaeus)
      Hydrophilidae (water scavenger beetles)
        Tropisternus lateralis nimbatus (Say)
        Hydrophilus triangularis Say
        Berosus styliferus Horn
        Berosus miles LeConte
        Berosus infuscatus LeConte
        Berosus stramineus Knisch
        Berosus exiguus Say?
        Berosus rugulosus Horn
        Helophorus species
        Octhebius species
      Trichoptera (caddisflies)
        Undetermined species
      Diptera (true flies)
        Ceratopogonidae (biting gnats)
          Undetermined species
        Chironomidae (midges)
          Chironomus (s.s.) decorus Johannsen
          Chironomus (s.s.) stigmaterus Say
          Cryptotendipes darbyi (Sublette)
          Procladius sublettei Roback
          Tanypus grodhausi Sublette
        Culicidae (mosquitoes)
          Culex tarsalis Coquillett
        Syrphidae (flower flies)
          Tubifera species

Acarina (water mites)
  Undetermined species

Amphibia
  Scaphiopus species (spadefoot toad)

Table 12.3. Windmill Fauna of Eastern New Mexico and Western Texas

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Oligochaeta (earthworms)
  Naididae
    Undetermined species

Mollusca
  Gastropoda (snail)
    Lymnaeidae
      Lymnaea bulimoides Say
    Planorbidae
      Helisoma trivolvis Say

Insecta
  Hemiptera (true bugs)
    Corixidae (water boatman)
      Corisella tarsalis (Fieber)
      Corisella edulis (Champion)
      Sigara (Vermicorixa) alternata (Say)
    Notonectidae (back swimmers)
      Notonecta undulata Say
  Odonata
    Anisoptera (dragonflies)
      Celithemis eponina Drury
      Libellula pulchella Drury
      Libellula saturata Uhler
      Pantala flavescens Fabricius
      Platyhemis lydia Drury
      Tarnetrum corruptum (Hagen)
    Zygoptera (damselflies)
      Enmallagma civile Hagen
      Ischnura demorsa Hagen
      Lestes alacer Hagen
      Lestes sigma Calvert
  Ephemeroptera (mayflies)
    Cloeon species
  Diptera
    Ceratopogonidae (biting gnats)
      Culicoides variipennis sonorensis (Wirth & Stone)
    Chironomidae (midges)
      Chironomus (s.s.) decorus Johannsen
      Chironomus (s.s.) stigmaterus Say
      Chironomus (s.s.) new species
      Tanypus grodhausi Sublette
      Procladius sublettei Roback
    Culicidae (mosquitoes)
      Culex tarsalis Coquillett
  Coleoptera
    Dytiscidae (predaceous diving beetles)
      Thermonectes nigrofasciatus ornaticollis Aube
      Laccophilus fasciatus terminalis Sharp?
    Hydrophilidae (water scavenger beetles)
      Tropisternus lateralis nimbatus (Say)
      Berosus styliferus Horn

Table 12.4. Checklist of Fish from the Lower Pecos Drainage

SPECIES	before 1972	1974-75	1977-78
STATION 5, PUPFISH SPRING			
Family Cyprinodontidae			
Cyprinodon pecosensis Echelle & Echelle (Pecos pupfish)		X	X
STATION 6, PECOS RIVER AT 6 MILE DAM			
Family Clupeidae			
Dorosoma cepedianum (LeSueur) (gizzard shad)		X	
Family Cyprinidae			
Cyprinus carpio Linnaeus (carp)		X	
Hybognathus placitus (Girard) (plains minnow)		X	
Notropis lutrensis (Baird & Girard) (red shiner)		X	
Pimephales promelas (Rafinesque) (fathead minnow)		X	
Family Ictaluridae			
Ictalurus melas (Rafinesque) (black bullhead)		X	
Ictalurus punctatus (Rafinesque) (channel catfish)		X	
Family Poeciliidae			
Gambusia affinis (Baird & Girard) (common gambusia)		X	
Family Centrarchidae			
Lepomis cyanellus Rafinesque (green sunfish)		X	
Lepomis macrochirus (Rafinesque) (bluegill)		X	
Micropterus salmoides (Lacépède) (largemouth bass)		X	
Pomoxis annularis Rafinesque (white crappie)		X	
STATION 7, PECOS RIVER AT 10 MILE DAM			
Family Lepisosteidae			
Lepisosteus osseus (Linnaeus) (longnose gar)			X
Family Clupeidae			
Dorosoma cepedianum (LeSueur) (gizzard shad)			X
Family Catostomidae			
Moxostoma congestum (Baird & Girard) (gray redhorse)	X	X	
Carpiodes carpio (Rafinesque) (carpsucker)		X	X
Cycleptus elongatus (blue sucker)	X		
Ictiobus bubalus (smallmouth buffalo)			X
Family Cyprinidae			
Pimephales promelas (Rafinesque) (fathead minnow)			X
Notropis lutrensis (Baird & Girard) (red shiner)			X
Cyprinus carpio Linnaeus (carp)	X	X	X
Family Ictaluridae			
Ictalurus punctatus (Rafinesque) (channel catfish)	X		X
Family Cyprinodontidae			
Lucania parva Baird (rainwater fish)	X		X
Fundulus zebrinus (Jordan & Gilbert) (Rio Grande killifish)	X		X
Family Poeciliidae			
Gambusia affinis (Baird & Girard) (common gambusia)	X		X
Family Atherinidae			
Menidia beryllina (Cope) (tidewater silversides)			X
Family Centrarchidae			
Chaenobryttus gulosus (Cuvier) (warmouth)			X
Lepomis cyanellus Rafinesque (green sunfish)	X		X
Lepomis macrochirus (Rafinesque) (bluegill)			X
Lepomis megalotis (Rafinesque) (longear sunfish)	X		
Lepomis megalotis X *L. macrochirus*			X
Lepomis cyanellus X *L. macrochirus*			X
Micropterus punctulatus (Rafinesque) (spotted bass)	X		
Micropterus salmoides (Lacépède) (largemouth bass)			X

Table 12.4, continued

Species	before 1972	1974-75	1977-78
STATION 8, HARROUN CANAL			
Family Clupeidae			
Dorosoma cepedianum (LeSueur) (gizzard shad)			X
Family Cyprinidae			
Cyprinus carpio Linnaeus (carp)			X
Notropis lutrensis (Baird & Girard) (red shiner)			X
Pimephales promelas (Rafinesque) (fathead minnow)			X
Family Ictaluridae			
Ictalurus punctatus (Rafinesque) (channel catfish)			X
Family Poeciliidae			
Gambusia affinis (Baird & Girard) (common gambusia)			X
Family Atherinidae			
Menidia beryllina (Cope) (tidewater silversides)			X
Family Centrarchidae			
Chaenobryttus gulosus (Cuvier) (warmouth)			X
Lepomis cyanellus Rafinesque (green sunfish)			X
Leponis macrochirus (Rafinesque) (bluegill)			X
STATION 9, PECOS RIVER AT HARROUN CROSSING			
Family Lepisoteidae			
Lepisosteus osseus (Linnaeus) (longnose gar)			X
Family Clupeidae			
Dorosoma cepedianum (LeSueur) (gizzard shad)			X
Family Catostomidae			
Cycleptus elongatus (LeSueur) (blue sucker)	X		X
Carpiodes carpio (Rafinesque) (carpsucker)	X		X
Ictiobus bubalus (Rafinesque) (smallmouth buffalo)			X
Moxostoma congestum (Bai·d & Girard) (gray redhorse)	X		X
Family Cyprinidae			
Cyprinus carpio Linnaeus (carp)			X
Notropis lutrensis (Baird & Girard)(red shiner)	X	X	X
Pimephales promelas (Rafinesque) (fathead minnow)	X	X	X
Hybognathus placitus Girard (plains minnow)		X	
Family Ictaluridae			
Ictalurus punctatus (Rafinesque) (channel catfish)			X
Family Cyprinodontidae			
Lucania parva Baird (rainwater fish)	X		X
Fundulus zebrinus (Jordan & Gilbert)(Rio Grande killifish)	X	X	
Cyprinodon pecosensis Echelle & Echelle (Pecos pupfish)	X		
Family Poeciliidae			
Gambusia affinis (Baird & Girard) (common gambusia)	X		X
Family Atherinidae			
Menidia beryllina (Cope) (tidewater silversides)		X	X
Family Centrarchidae			
Chaenobryttus gulosus (Cuvier) (warmouth)			X
Lepomis cyanellus Rafinesque (green sunfish)			X
Lepomis macrochirus (Rafinesque) (bluegill)		X	X
Lepomis megalotis (Rafinesque) (longear sunfish)	X		X
Lepomis megalotis X L. cyanellus			X
Micropterus punctulatus (Rafinesque) (spotted bass)	X		X
Micropterus salmoides (Lacépède) (largemouth bass)			X
Family Percidae			
Etheostoma lepidum (Baird & Girard) (green throated darter)	X		
STATION 10, PECOS RIVER AT MALAGA BEND			
Family Lepisosteidae			
Lepisosteus osseus (Linnaeus) (longnose gar)			X

Table 12.4, continued

Species	before 1972	1974-75	1977-78
STATION 10, continued			
Family Clupeidae			
Dorosoma cepedianum (LeSueur) (gizzard shad)			X
Family Catostomidae			
Carpiodes carpio (Rafinesque) (carpsucker)			X
Family Cyprinidae			
Cyprinus carpio Linnaeus (carp)			X
Family Cyprinodontidae			
Lucania parva Baird (rainwater fish)			X
Fundulus zebrinus (Jordon & Gilbert) (Rio Grande killifish)			X
Cyprinodon pecosensis Echelle & Echelle (Pecos pupfish)			X
Family Poeciliidae			
Gambusia affinis (Baird & Girard) (common gambusia)			X
Family Atherinidae			
Menidia beryllina (Cope) (tidewater silversides)			X
Family Percichthyidae			
Morone chrysops (Rafinesque) (white bass)			X
STATION 11, PECOS RIVER AT EL PASO NATURAL GAS PIPELINE CROSSING			
Family Lepisosteidae			
Lepisosteus osseus (Linnaeus) (longnose gar)			X
Family Clupeidae			
Dorosoma cepedianum (LeSueur) (gizzard shad)	X	X	X
Family Catostomidae			
Cycleptus elongatus (LeSueur) (blue sucker)	X		
Carpiodes carpio (Rafinesque) (carpsucker)	X	X	
Family Cyprinidae			
Cyprinus carpio Linnaeus (carp)		X	
Notropis stramineus (Cope) (sand shiner)	X		
Notropis lutrensis (Baird & Girard) (red shiner)	X	X	
Hybopsis aestivalis (Girard) (speckled chub)	X		
Pimephales promelas (Rafinesque) (fathead minnow)	X	X	
Family Ictaluridae			
Ictalurus punctatus (Rafinesque) (channel catfish)	X		
Family Cyprinodontidae			
Lucania parva Baird (rainwater fish)		X	X
Fundulus zebrinus (Jordan & Gilbert) (Rio Grande killifish)	X	X	X
Cyprinodon pecosensis Echelle & Echelle (Pecos pupfish)		X	X
Family Poeciliidae			
Gambusia affinis (Baird & Girard) (common gambusia)	X	X	X
Family Atherinidae			
Menidia beryllina (Cope) (tidewater silversides)		X	X
Family Centrarchidae			
Lepomis megalotis (Rafinesque) (longear sunfish)	X		
Lepomis cyanellus Rafinesque (green sunfish)	X		
Lepomis macrochirus (Rafinesque) (bluegill)	X	X	
Micropterus punctulatus (Rafinesque) (spotted bass)	X		
Micropterus salmoides (Lacépède) (largemouth bass)		X	
Family Percidae			
Etheostoma lepidum (Baird & Girard) (green throated darter)	X		
STATION 12, UPPER RED BLUFF RESERVOIR			
Family Lepisosteidae			
Lepisosteus osseus (Linnaeus) (longnose gar)	X	X	

Table 12.4, continued

SPECIES	before 1972	1974-75	1977-78
STATION 12, continued			
Family Clupeidae			
Dorosoma cepedianum (LeSueur) (gizzard shad)	X	X	X
Family Catostomidae			
Carpiodes carpio (Rafinesque (carpsucker)	X	X	
Ictiobus niger (Rafinesque) (black buffalo)		X	
Ictiobus bubalus (Baird & Girard) (smallmouth buffalo)			
Moxostoma congestum (Baird & Girard) (gray redhorse)	X		
Family Cyprinidae			
Cyprinus carpio Linnaeus (carp)	X	X	X
Hybognathus placitus Girard (plains minnow)		X	
Notropis lutrensis (Baird & Girard) (red shiner)	X	X	
Pimephales promelas (Rafinesque) (fathead minnow)	X	X	
Family Ictaluridae			
Pylodictus olivaris (Rafinesque) (flathead catfish)	X		
Ictalurus punctatus (Rafinesque) (channel catfish)	X	X	
Family Cyprinodontidae			
Lucania parva Baird (rainwater fish)		X	X
Fundulus zebrinus (Jordan & Gilbert)(Rio Grande killifish)	X		X
Family Poeciliidae			
Gambusia affinis (Baird & Girard) (common gambusia)	X	X	X
Family Atherinidae			
Menidia beryllina (Cope) (tidewater silversides)		X	X
Family Centrarchidae			
Lepomis megalotis (Rafinesque) (longear sunfish)	X		
Lepomis cyanellus Rafinesque) (green sunfish)		X	
Lepomis macrochirus (Rafinesque) (bluegill)	X		
Micropterus punctulatus (Rafinesque) (spotted bass)	X		
Micropterus salmoides (Lacépède) (largemouth bass)	X		
Family Percidae			
Etheostoma lepidum (Baird & Girard) (green throated darter)	X		
Family Percichthyidae			
Morone chrysops (Rafinesque) (white bass)	X	X	X

Table 12.5. Composition and Relative Abundance of Fish Species, All Dates of Collection Combined

SPECIES	STATION NUMBER													
	5		7		8		9		10		11		12	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Lepisosteus osseus (longnose gar)	0	0	20	3.9	0	0	138	12.8	17	2.9	1	0.1	0	0
Dorosoma cepedianum (gizzard shad)	0	0	291	56.6	28	7.5	78	7.2	237	40.2	271	16.1	17	5.7
Carpiodes carpio (Carpsucker)	0	0	59	11.5	0	0	123	11.4	1	0.2	0	0	0	0
Ictiobus bubalus (smallmouth buffalo)	0	0	37	7.2	0	0	3	0.3	0	0	0	0	0	0
Moxostoma congestum (gray redhorse)	0	0	0	0	0	0	2	0.2	0	0	0	0	0	0
Cyprinus carpio (carp)	0	0	9	1.8	12	3.2	5	0.5	4	0.7	0	0	2	0.7
Notropis lutrensis (red shiner)	0	0	7	1.4	61	16.4	557	51.6	0	0	0	0	0	0
Pimephales promelas (fathead minnow)	0	0	2	0.4	37	10	87	8.1	0	0	0	0	0	0
Ictalurus punctatus (channel catfish)	0	0	3	0.6	2	0.5	4	0.4	0	0	0	0	0	0
Cyprinodon pecosensis (Pecos pupfish)	130	100	0	0	0	0	0	0	123	20.8	68	4.0	0	0
Fundulus zebrinus (Rio Grande killifish)	0	0	0	0	0	0	0	0	7	1.2	11	0.7	2	0.7
Lucania parva (rainwater fish)	0	0	23	4.5	0	0	6	0.6	18	3.1	251	14.9	100	33.3
Gambusia affinis (common gambusia)	0	0	27	5.3	7	1.9	11	1	55	9.3	1002	59.5	13	4.3
Menidia beryllina (tidewater silversides)	0	0	3	0.6	182	49.1	30	2.8	113	19.2	80	4.8	165	55.0
Chaenobryttus gulosus (warmouth)	0	0	7	1.4	10	2.7	5	0.5	0	0	0	0	0	0
Lepomis cyanellus (green sunfish)	0	0	10	1.9	14	3.8	7	0.7	0	0	0	0	0	0
Lepomis macrochirus (Bluegill)	0	0	10	1.9	18	4.9	17	1.6	0	0	0	0	0	0
L. macrochirus X L. cyanellus	0	0	3	0.6	0	0	0	0	0	0	0	0	0	0
L. megalotis X L. cyanellus	0	0	0	0	0	0	1	0.1	0	0	0	0	0	0
Micropterus salmoides (largemouth bass	0	0	3	0.6	0	0	6	0.6	0	0	0	0	0	0
Morone chrysops (white bass)	0	0	0	0	0	0	0	0	15	2.5	0	0	1	0.3
TOTAL	130		514		371		1080		590		1684		300	

Table 12.6. Fishes Collected from Two Adjacent, Blocked Off Areas at Harroun Crossing

SPECIES	SECTION 1			
	Number	% by Number	Weight (g)	% by Weight
Lepisosteus osseus (longnose gar)	1	0.3	424	12.56
Dorosoma cepedianum (gizzard shad)	26	8.4	2090	61.94
Carpiodes carpio (carpsucker)	1	0.3	200	5.93
Cyprinus carpio (carp)	1	0.3	399	11.83
all "minnows"*	274	88.4	153	4.53
Ictalurus punctatus (channel catfish)	1	0.3	6	0.17
Lepomis cyanellus (green sunfish)	2	0.65	25	0.74
Lepomis macrochirus (bluegill)	3	0.97	16	0.47
Micropterus salmoides (largemouth bass)	1	0.3	61	1.81
Chaenobryttus gulosus (warmouth)	0	0	0	0
	SECTION 2			
Lepisosteus osseus (longnose gar)	0	0	0	0
Dorosoma cepedianum (gizzard shad)	20	8.13	2102	86.75
Carpiodes carpio (carpsucker)	0	0	0	0
Cyprinus carpio (carp)	0	0	0	0
all "minnows"	216	87.81	115.25	4.75
Ictalurus punctatus (channel catfish)	1	0.41	14	0.57
Lepomis cyanellus (green sunfish)	1	0.41	37	1.52
Lepomis macrochirus (bluegill)	6	2.44	38.75	1.60
Micropterus salmoides (largemouth bass)	1	0.41	108	4.46
Chaenobryttus gulosus (warmouth)	1	0.41	8	0.33

*"minnows" includes: Notropis lutrensis, Pimephales promelas, Lucania parva, and Gambusia affinis. Notropis lutrensis was 88.3% and 87.8% respectively for the "minnow" groups in the above areas.

Table 12.7. Checklist of Aquatic Herptiles from the Lower Pecos Drainage

STATION 3, HILL TANK
- Amphibia
  - Family Ambystomatidae
    - Ambystoma tigrinum (Green) (tiger salamander)
  - Family Pelobatidae
    - Scaphiopus bombifrons Cope (plains spadefoot)
  - Family Bufonidae
    - Bufo cognatus Say (great plains toad) - sighted
    - Bufo debilis Girard (green toad)
    - Bufo speciosus Girard (Texas toad) - sighted
- Reptilia
  - Family Chelydridae
    - Kinosternon flavescens (Agassiz) (yellow mud turtle)

NEAR STATION 5, PUPFISH SPRING
- Amphibia
  - Family Pelobatidae
    - Scaphiopus couchi Baird (Couch's spadefoot)

STATION 7, PECOS RIVER AT 10 MILE DAM
- Reptilia
  - Family Colubridae
    - Natrix erythogaster (Foster) (plain-bellied water snake)

STATION 8, HARROUN CANAL
- Reptilia
  - Family Chelydridae
    - Kinosternon flavescens (Agassiz) (yellow mud turtle)
  - Family Colubridae
    - Thamnophis marcianus (Baird & Girard) (checkered garter snake)

STATION 9, PECOS RIVER AT HARROUN CROSSING
- Amphibia
  - Family Hylidae
    - Acris crepitans blanchardi Harper (Blanchard's cricket frog)
- Reptilia
  - Family Trionychidae
    - Trionyx spiniferus? LeSueur (spiny softshell)
  - Family Testudinidae
    - Pseudemys concinna (LeConte) (river cooter)

STATION 12, UPPER RED BLUFF RESERVOIR
- Amphibia
  - Family Pelobatidae
    - Scaphiopus couchi Baird (Couch's spadefoot)
- Reptilia
  - Family Trionychidae
    - Trionyx spiniferus? LeSueur (spiny softshell turtle)
  - Family Testudinidae
    - Pseudemys scripta (Schoepff) (pond slider)

Table 1.8. Checklist of the aquatic plants by sampling station.

Station 5, Pupfish Spring

Chenopodiaceae (Goosefoot Family)
Allenrolfea occidentalis (Wats.) O. Ktze (Pickle-weed)
Salicornia utahensis Tidestr. (Utah samphire)
Gramineae (Grass Family)
Distichlis spicata (L.) Green (Saltgrass)
Plumbaginaceae (Plumbago Family)
Limonium limbatum Small (Sea-lavender)

Station 6, Pecos River at 6 Mile Dam

Cyperaceae (Sedge Family)
Eleocharis montevidensis Kunth. (Spikerush)
Scirpus americanus Pers. (Sword-grass)
Tamaricaceae (Tamarisk Family)
Tamarix ramosissima Ledeb. (Salt cedar)

Station 7, Pecos River at 10 Mile Dam

Aizoaceae (Carpet-weed Family)
Sesuvium verrucosum Raf. (Sea purslane)
Cyperaceae (Sedge Family)
Eleocharis parvula (R. & S.) Small (Spikerush)
Scirpus americanus Pers. (Sword-grass)
Scirpus maritimus L. (Salt-marsh bulrush)
Gramineae
Distichlis spicata (L.) Green (Saltgrass)
Polypogon monspeliensis (L.)Desf. (Rabbitfoot grass)
Polygonaceae (Knotweed Family)
Polygonum lapathifolium L. (Smartweed)
Tamaricaceae (Tamarisk Family)
Tamarix ramosissima Ledeb. (Salt cedar)

Station 8, Harroun Canal

Cyperaceae (Sedge Family)
Scirpus americanus Pers. (Sword-grass)

Primulaceae (Primrose Family)
Samolus cuneatus Small (brookweed)
Tamaricaceae (Tamarisk Family)
Tamarix ramosissima Ledeb. (Salt cedar)

Station 9, Pecos River at Harroun Crossing

Boraginaceae (Borage Family)
Heliotropium carassavicum L. (Cola de Mico)
Cyperaceae (Sedge Family)
Cyperus odoratus L. (flatsedge)
Eleocharis parvula (R & S) Small (Spikerush)
Scirpus americanus Pers. (Sword-grass)
Scirpus maritimus L. (Salt-marsh bulrush)
Gramineae (Grass Family)
Distichlus spicata (L.) Green (Saltgrass)
Polypogon monspeliensis (L.) Desf. (Rabbitfoot grass)
Potamogetonaceae (Pondweed Family)
Potamogeton foliosus Raf. (Pondweed)

Station 9, continued

Primulaceae (Primrose Family)
Samolus cuneatus Small (Brookweed)

Tamaricaceae (Tamarisk Family)
Tamarix ramosissima Ledeb. (Salt cedar)
Umbelliferae (Carrot Family)
Apium graveolens L. (Wild celery)

Station 10, Pecos River at Malaga Bend

Aizoaceae (Carpet-weed Family)
Sesuvium verrucosum Raf. (Sea purslane)
Boraginaceae (Borage Family)
Heliotropium curassavicum L. (Cola de Mico)
Chenopodiaceae (Goosefoot Family)
Allenrolfea occidentalis (Wats.) O. Ktze (Pickle-weed)
Gramineae (Grass Family)
Distichlus spicata (L.) Greene (Saltgrass)
Primulaceae (Primrose Family)
Samolus cuneatus Small (Brookweed)
Ruppiaceae (Ditch-grass)
Ruppia maritima L. (Widgeon-grass)
Tamaricaceae (Tamarisk Family)
Tamarix ramosissima Ledeb. (Salt cedar)

Station 11, Pecos River at El Paso Natural Gas Pipeline

Chenopodiaceae (Goosefoot Family)
Suaeda depressa (Pursh.) Wats. (Seepweed)
Gramineae (Grass Family)
Distichlus spicata (L.) Green (Saltgrass)
Ruppiaceae (Ditch-grass Family)
Ruppia maritima L. (Widgeon-grass)
Tamaricaceae (Tamarisk Family)
Tamarix aphylla (L.) Karst. (Salt cedar)

Station 12, Upper Red Bluff Reservoir

Cyperaceae (Sedge Family)
Scirpus maritimus L. (Salt-marsh bulrush)
Ruppiaceae (Ditch-grass Family)
Ruppia maritima L. (Widgeon-grass)
Tamaricaceae (Tamarisk Family)
Tamarix ramosissima Ledeb. (Salt cedar)

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APPENDIX 1

STATISTICAL ANALYSES - SERIES A

CHI-SQUARE TEST FOR DIFFERENCES IN PROBABILITIES

10 mile Dam, Surber, 3 January 1978

Organism	Subsample number 1	2	3	4	5	6	7	8	Totals-R_j
Amphipoda	(443.59)	(396.28)	(404.82)	(452.90)	(376.90)	(438.16)	(440.49)	(397.84)	
	442	405	417	444	381	419	454	389	3351
Chironomidae	(44.74)	(39.97)	(40.83)	(45.68)	(38.02)	(44.20)	(44.43)	(40.13)	
	50	37	37	47	39	56	36	36	338
Ceratopogonidae	(6.62)	(5.92)	(6.04)	(6.75)	(5.62)	(6.54)	(6.57)	(5.94)	
	5	5	4	6	6	10	5	9	50
Oligochaeta	(22.47)	(19.99)	(20.42)	(22.84)	(19.0)	(22.10)	(22.21)	(20.06)	
	23	21	12	26	17	25	21	24	169
Nematoda	(44.87)	(40.09)	(40.95)	(45.82)	(38.16)	(44.33)	(44.56)	(40.25)	
	41	34	42	48	36	47	42	49	339
Hydrophilidae	(5.16)	(4.61)	(4.71)	(5.27)	(4.39)	(5.10)	(5.13)	(4.63)	
	4	6	6	6	3	3	7	4	39
Miscellaneous	(4.64)	(4.14)	(4.23)	(4.73)	(3.94)	(4.58)	(4.60)	(4.16)	
	7	3	4	7	4	5	3	2	35
Totals-N_i	572	511	522	584	486	565	568	513	4321 = G

Ho: All of the probabilities in the same row are equal to each other.
Ha: At least two of them are different.
$\alpha = 5\%$
Test Statistic: $T = \sum_{i=1}^{N} \sum_{j=1}^{R} \frac{(O_{ij}-E_{ij})^2}{E_{ij}} \sim_{\ell} \chi^2_{.95(r-1)(c-1)}$, where $E_{ij} = \frac{N_i R_j}{G}$ = (expected value for each cell)

Critical value: $\chi^2_{.95(42)} = 58.1$ O_{ij} = observed value for the $_{ij}$th cell.

Calculated value = 31.826
Conclusion: accept Ho
Note 1: Expected values are given in parentheses.
Note 2: Categories with few individuals are grouped together as Miscellaneous to avoid expected values less than one. This test may not be valid if: a) the proportion of E_{ij}'s < 5 is > 20 % of all the expected values. b) any E_{ij} is less than one.

Note 3: Miscellaneous includes: Muscidae, Ephemeroptera, Zygoptera, Dytiscidae, Stratiomyidae, Psychodidae, Mollusca, Hirudinea, and unidentified miscellaneous.
Note 4: This test was performed with 12 expected values <5 or 21.4% of the expected values <5. Since the validity of the test may be affected, further analysis was made grouping the Hydrophilidae into miscellaneous; subsequent test results given below agree with the analysis above.

Critical value: $\chi^2_{.95(35)} = 49.765$
Calculated value = 26.582
Conclusion: accept Ho

STATISTICAL ANALYSES - SERIES B

CHI-SQUARE TEST FOR DIFFERENCES IN PROBABILITIES

Harroun Crossing, Surber, 3 January 1978

Organism	Subsample Number 1	2	3	4	5	6	7	8	Totals-R_i
Cheumatopsyche	(1019.26) 990	(928.21) 930	(885.19) 899	(990.92) 1015	(991.65) 956	(964.67) 958	(1021.55) 1039	(1008.42) 1023	7810
Icthytrichia	(8.22) 10	(7.49) 6	(7.14) 7	(7.99) 8	(8.00) 11	(7.78) 8	(8.24) 5	(8.13) 8	63
Other Trichoptera	(4.70) 4	(4.28) 2	(4.08) 8	(4.57) 4	(4.57) 8	(4.45) 4	(4.71) 6	(4.65) 0	36
Chironomidae	(186.25) 191	(169.60) 178	(161.74) 167	(181.06) 169	(181.19) 186	(176.26) 196	(186.65) 170	(184.25) 170	1427
Oligochaeta	(134.44) 155	(122.42) 107	(116.74) 88	(130.69) 125	(130.78) 153	(127.22) 120	(134.72) 145	(132.99) 137	1030
Pyralidae	(13.57) 10	(12.36) 10	(11.79) 17	(13.20) 12	(13.21) 17	(12.85) 15	(13.60) 13	(13.43) 10	104
Odonata	(6.13) 5	(5.59) 3	(5.33) 5	(5.96) 5	(5.97) 9	(5.81) 5	(6.15) 9	(6.07) 6	47
Mollusca	(13.70) 15	(12.48) 22	(11.90) 15	(13.32) 12	(13.33) 12	(12.97) 10	(13.73) 9	(13.56) 10	105
All Others	(9.01) 18	(8.20) 15	(7.82) 8	(8.75) 9	(8.76) 8	(8.52) 7	(9.03) 5	(8.91) 19	69
Total -N_i	1398	1273	1214	1359	1360	1323	1401	1383	10,711

Ho: all of the probabilities in the same row are equal to each other.
Ha: at least two of them are different.
α = 5%

Test statistic: $T = \sum_{i=1}^{N}\sum_{j=1}^{R}\left[(O_{ij}-E_{ij})^2/E_{ij}\right] \sim \chi^2_{.95(R-1)(c-1)}$.

Critical value = $\chi^2_{.95(56)}$ = 74.45.

Obtained value = 93.89191252
Conclusion: reject Ho.

Note 1: All other includes: Dryopidae, Hydrophilidae, scuds, Nematoda, Simuliidae, Hirudinea, Ephemeroptera.
Note 2: This is the most expanded (most taxa) listing that can be analyzed without exceeding 12 E_{ij}'s that are less than 5.

STATISTICAL ANALYSES - SERIES C

STEP ANALYSIS BETWEEN SAMPLES FOR TOTAL BENTHOS

Station	Sampler type	Date	Number of samples	$\bar{X} \pm t(0.8;n-1)\ S/\sqrt{n}$	S	SE	20 of $\bar{X}$	D	CV
3, Hill Tank	Ekman	19 January 1978	2*	4796.46±3693.872	4796.46	2684.5	661.9	81.20	99.99
5, Pupfish Springs	Ekman	20 January 1978	4	120.00± [illegible]	28.00	16.16	[illegible]	[illegible]	[illegible]
5, Pupfish Springs	Ekman	21 March 1978	2*	1222.00±996.305	616.69	429.0	[illegible]	37.10	50.65
7, 10 Mile Dam	Surber	21 March 1978	2*	3475.54±304.912	3499.47	2473.5	895.1	55.29	75.10
9, Harroun Crossing	Surber	22 March 1978	2*	1062.36±450.45	462.96	327.36	212.5	30.81	43.58
11, Pipeline Crossing	Surber	23 March 1978	2	9775.0±2497.44	2566.80	1815.0	1955.0	18.57	26.27
12, Upper Red Bluff	Ekman	3 January 1978	2*	5666.54±527.056	6708.52	3743.5	1133.5	65.71	118.35
13, Lower Red Bluff	Ekman	5 January 1978	3*	13.0±7.22	11.79	6.81	[illegible]	[illegible]	90.69

* indicates more samples needed for analysis.

S = standard deviation = $\sqrt{\frac{\sum_{i=1}^{n}(X_i-\bar{X})^2}{n-1}}$

$D = \frac{SE}{\bar{X}} \times 100$

CV = coefficient variation = $\frac{S \times 100}{\bar{X}}$

SE = standard error = $\sqrt{\frac{S^2}{n}}$

if: $SE < 20\%$ of $\bar{X}$
then: sufficient number of samples analyzed

OR

if: $D \leq 20$
then: sufficient number of samples analyzed

HARROUN CROSSING, SURBER # 2, 3 January 1978

Total Benthos - Subsample numbers

	1	2	3	4	5	6	7	8
Observed values	1398	1273	1214	1359	1360	1323	1401	1383
Expected values	1338.875	1338.875	1338.875	1338.875	1338.875	1338.875	1338.875	1338.875

Test: Ho: $F(X) = F^*(X)$

$\alpha = .5$

Test statistic: $T = \sum_{j=1}^{N} \frac{(O_j - E_j)^2}{E_j}$

Critical value = $\chi^2_{.95}(7) = 14.07$

Obtained value = 22.060026

Conclusion = reject Ho

Total Benthos (excluding Oligochaeta) - Subsample numbers

	1	2	3	4	5	6	7	8
Observed values	1366	1126	1234	1207	1203	1256	1246	1243
Expected values	1210.125	1210.125	1210.125	1210.125	1210.125	1210.125	1210.125	1210.125

Test: Ho: $F(X) = F^*(X)$

$\alpha = .5$

Test statistic: $T = \sum_{j=1}^{N} \frac{(O_j - E_j)^2}{E_j}$

Critical value = $\chi^2_{.95}(7) = 14.07$

Obtained value = 11.674

Conclusion = accept Ho

$F^*(X) = 0, X < 0$
$X, 0 \leq X < 1$
$1, 1 \leq X$

Note: expected value = p*N = arithmetic mean
P* = expected probability = 1/8
Note: second set of observed values and expected values based on omitting Oligochaeta from the analysis.

APPENDIX II

WATER QUALITY DATA
1978

	January	February	March	June	August	September
Station no. 2, Windmill Tank						
Air temperature, C°		15	33			
Water temperature, C°		10	19			
Conductivity, 25°C/μmhos/cm		1,600	1,800	1,000		
pH		7.7	8.2			
Turbidity, NTU		9	3	16		
Hardness as $CaCO_3$, mg/l			600	480		
Dissolved oxygen, mg/l		13.6	13.9	8.4		
Chloride as Cl, mg/l		590	250	500		
Sulfate as SO_4, mg/l		542.5		537.5		
Nitrate as N, mg/l			0.2	0.6		
Nitrite as N, mg/l			9.9	9.9		
Phosphate (ortho), mg/l			1.02	0.07		
Potassium (K), mg/l			8			
Sodium (Na), mg/l			245			
Aluminum as Al, μg/l			< 100			
Arsenic as As, μg/l			< 0.30			
Barium as Ba, μg/l			380			
Cadmium as Cd, μg/l			6			
Chromium as Cr, μg/l			7			
Copper as Cu, μg/l			38			
Iron as Fe, μg/l			83			
Lead as Pb, μg/l			18			
Manganese as Mn, μg/l			36			
Mercury, as Hg, μg/l			1.6			
Molybdenum as Mo, μg/l			≤ 50			
Nickel as Ni, μg/l			10			
Selenium as Se, μg/l			4.3			
Silver as Ag, μg/l			21			
Station no. 3, Hill Tank						
Conductivity, 25°C/μmhos/cm					750	325
Turbidity, NTU				297	32	53
Hardness as $CaCO_3$, mg/l				9,000	3.400	3,000
Dissolved oxygen, mg/l					8.7	4.9
Chloride as Cl, mg/l				1,500	300	200
Sulfate as SO_4, mg/l				430	11.9	18.8
Nitrate as N, mg/l					12.2	1.2
Nitrite as N, mg/l					0.03	1.2
Phosphate (ortho), mg/l					0.31	1.1
Station no. 4, Laguna Grande de la Sal						
Air temperature, C°		19	32			
Water temperature, C°		15	27			
Conductivity, 25°C/μmhos/cm		400,000	450,000		200,000	
pH		7.7	7.7			
Turbidity		9	3	9	3	
Total dissolved solids, mg/l 180°C			263,980			
Hardness as $CaCO_3$, mg/l		26,400	24,000	20,000	9,840	

Station no. 4, continued	January	February	March	June	August	September
Dissolved oxygen, mg/l		1.4	1.2	0.8	0.2	
Chloride as Cl, mg/l		153,000	180,000	135,000	165,000	
Sulfate as SO_4, mg/l		7,600	4,565	10,280	7,700	
Nitrate as N, mg/l			1.6	2.4	1.6	
Nitrite as N, mg/l			17.4	19	26.7	
Phosphate (Ortho), mg/l			0.18	0.12	0.13	
Calcium as Ca, mg/l		1080				
Fluoride as F, mg/l		4.8				
Magnesium as Mg, mg/l		5760				
Potassium as K, mg/l		3900				
Sodium as Na, mg/l		82,000				
Aluminum as Al, μg/l		500				
Arsenic as As, μg/l		18				
Cadmium as Cd, μg/l		280				
Chromium as Cr, μg/l		120				
Copper as Cu, μg/l		115				
Iron as Fe, μg/l		1360				
Lead as Pb, μg/l		880				
Manganese as Mn, μg/l		798				
Mercury as Hg, μg/l		0.66				
Molybdenum as Mo, μg/l		380				
Nickel as Ni, μg/l		750				
Selenium as Se, μg/l		< 0.5				
Silver as Ag, μg/l		20				
Zinc as Zn, μg/l		238				

Station no. 5, Pupfish Spring						
Air temperature, C°			32			
Water temperature, C°			27			
Conductivity, 25°C/μmhos/cm	76,000		60,000	18,000	25,000	20,000
pH	7.9		7.8			
Turbidity, NTU	0.4		7	3	7	[illegible]
Total dissolved solids mg/l 180°C	49,200					
Hardness as $CaCO_3$, mg/l	13,000		11,800	13,400	13,400	12,700
Dissolved oxygen, mg/l			8.4	2.9		2.6
Alkalinity as $CaCO_3$, mg/l	198					
Bicarbonate as HCO_3, mg/l	241					
Chloride as Cl, mg/l	25,000		30,000	28,000	31,000	28,500
Sulfate as SO_4, mg/l	2,800		2,865	4,135	3,840	2,150
Ammonia as N, mg/l	0.04					
Nitrate as N, mg/l	0.63		3.9	1.8	2.0	2.2
Nitrite as N, mg/l			23.6	25.2	30.2	14.3
Phosphate (total), mg/l	0.04					
Phosphate (ortho), mg/l	0.027		0.39	0.36	0.77	0.19
Calcium as Ca, mg/l	2,100					
Magnesium as Mg, mg/l	1,900					
Potassium as K, mg/l	300		400			
Sodium as Na, mg/l	1,480		7,980			
Aluminum as Al, μg/l			500			
Arsenic as As, μg/l			27			
Cadmium as Cd, μg/l			81			
Chromium as Cr., μg/l			32			
Copper as Cu, μg/l			50			
Iron as Fe, μg/l			466			
Lead as Pb, μg/l			337			
Manganese as Mn, μg/l			293			
Mercury as Hg, μg/l			1.12			

Station no. 5, continued	January	February	March	June	August	September
Molybdenum as Mo, μg/l			110			
Nickel as Ni, μg/l			746			
Selenium as Se, μg/l			≤ 0.30			
Silver as Ag, μg/l			8.6			
Zinc as Zn μg/l			95			

Station no. 7, Pecos River at 10 Mile Dam

Air temperature, C°			26			
Water temperature, C°			20			
Conductivity, 25°C/μmhos/cm	12,000		5,900	3,100		7,000
pH	7.99		8.5			
Turbidity	2.7		5	20	40	46
Total dissolved solids, mg/l @180°C	7240		550			
Hardness as $CaCO_3$, mg/l	3,210		1,760	2,200	2,920	3,800
Dissolved oxygen, mg/l			15.8	6.0	8.5	7.0
Alkalinity as $CaCO_3$, mg/l	233					
Bicarbonate as HCO_3, mg/l	284					
Chloride as Cl, mg/l	1,880		2,500	1,400	2,500	2,400
Sulfate as SO_4, mg/l	2,550		1,150	1,925	2,057.5	2,282.5
Ammonia as N, mg/l	0.168					
Nitrate as N, mg/l	3.67		2.7	0.6	0.7	2.7
Nitrite as N, mg/l		26.7	11.2	19		6.8
Phosphate (total), mg/l	0.52					
Phosphate (ortho), mg/l	0.006		0.21	0.08	1.77	0.31
Calcium as Ca, mg/l	718					
Magnesium as Mg, mg/l	345					
Potassium as K, mg/l	12		7			
Sodium as Na, mg/l	1020		550			
Aluminum as Al, μg/l			≤ 100			
Arsenic as As, μg/l			2.6			
Cadmium as Cd, μg/l			5.8			
Chromium as Cr, μg/l			9			
Copper as Cu, μg/l			≤ 5			
Iron as Fe, μg/l			139			
Lead as Pb, μg/l			29			
Manganese as Mn, μg/l			64			
Mercury as Hg, μg/l			0.12			
Molybdenum as Mo, μg/l			≤ 50			
Nickel as Ni, μg/l			19			
Selenium as Se, μg/l			≤ 0.30			
Silver as Ag, μg/l			2.6			
Zinc as Zn, μg/l			14			

Station no. 9, Pecos River at Harroun Crossing

Air temperature, C°		15	23			
Water temperature, C°		13	26			
Conductivity, 25°C/μmhos/cm	13,000	10,000		4,200	5,700	3,800
pH	7.93	7.8	7.8			
Turbidity	8	14	3	18	7	38
Total dissolved solids, mg/l @180°C	6,400					
Hardness as $CaCO_3$, mg/l	2,300	2,200	2,520	2,180	2,160	2,260
Dissolved oxygen, mg/l		11	12.2	7.2	8.7	7.2
Alkalinity as $CaCO_3$, mg/l	164					
Bicarbonate as HCO_3, mg/l	200					
Chloride as Cl, mg/l	1,960	3,000	2,600	1,800	1,200	1,800

Station 9, continued	January	February	March	June	August	September
Sulfate as Na, mg/l	2,030	1,500	1,845	1,812.5	1,575	1,612.5
Ammonia as N, mg/l	0.131					
Nitrate as N, mg/l	5.1		1.2	0.2	1.0	3.9
Nitrite as N, mg/l			30.1	12.7	7.9	4.0
Phosphate (total), mg/l	0.049					
Phosphate (ortho), mg/l	0.004		0.25	0.37	0.10	0.21
Calcium as Ca, mg/l	593					
Magnesium as Mg, mg/l	199					
Potassium as K, mg/l	38		47			
Sodium as Na, mg/l	1,080		1,520			
Aluminum as Al, µg/l			640			
Arsenic as As, µg/l			2.9			
Barium as Ba, µg/l			1,060			
Cadmium as Cd, µg/l			15			
Chromium as Cr, µg/l			9			
Copper as Cu, µg/l			7			
Iron as Fe, µg/l			388			
Lead as Pb, µg/l			75			
Manganese as Mn, µg/l			45			
Mercury as Hg, µg/l			0.28			
Molybdenum as Mo, µg/l			≤ 50			
Nickel as Ni, µg/l			55			
Selenium as Se, µg/l			≤0.30			
Silver as Ag, µg/l			2.8			
Zinc as Zn, µg/l			20			

Station 10, Pecos River at Malaga Bend (Pierce Canyon)

Air temperature, C°	28			
Water temperature, C°	21			
Conductivity, 25°C/µmhos/cm	31,250	5,200	18,000	6,000
pH	7.8			
Turbidity	3	22	38	56
Hardness as $CaCO_3$, mg/l	2,800	2,040	2,940	2,600
Dissolved oxygen, mg/l	10	7	8.3	8.1
Chloride as Cl, mg/l	9,000	3,400	5,400	4,700
Sulfate as SO_4, mg/l	2,475	1,762.5	1,970	1,970
Nitrate as N, mg/l	1.2	0.3	0.2	1.0
Nitrite as N, mg/l	25.2	8.4	17.4	6.8
Phosphate (ortho), mg/l	0.29	0.08	0.37	0.18
Potassium as K, mg/l	191			
Sodium as Na, mg/l	4,270			
Aluminum as Al, µg/l	≤100			
Arsenic as As, µg/l	1.5			
Barium as Ba, µg/l	1,810			
Cadmium as Cd, µg/l	43			
Chromium as Cr, µg/l	48			
Copper as Cu, µg/l	12			
Iron as Fe, µg/l	93			
Lead as Pb, µg/l	229			
Manganese as Mn, µg/l	57			
Mercury as Hg, µg/l	4			
Molybdenum as Mo, µg/l	≤ 50			
Nickel as Ni, µg/l	229			
Selenium as Se, µg/l	1.3			
Silver as Ag, µg/l	8.1			
Zinc as Zn, µg/l	30			

Station no. 11, Pecos River at El Paso Natural Gas Co. Pipeline Crossing

	January	February	March	June	August	September
Air temperature, C°		15	21			
Water temperature, C°		10	18			
Conductivity, 25°C/μmhos/cm	33,000	20,000	32,500	2,500	12,000	10,000
pH	8.17	8.0	7.6			
Turbidity	1.5	14	5	12	38	28
Total dissolved solids, mg/l @ 180°C	18,300					
Hardness as $CaCO_3$, mg/l	3,140	3,200	2,700	2,320	1,480	3,000
Dissolved oxygen, mg/l		12	9.4	8.2	8.0	7.4
Alkalinity as $CaCO_3$ mg/l	142					
Bicarbonate as HCO_3, mg/l	174					
Chloride as Cl, mg/l	8,800		8,500	3,000	3,200	5,600
Sulfate as SO_4	2,890	2,150	2,215	1,667.5	970	2,047.5
Ammonia as N, mg/l	0.083					
Nitrate as N, mg/l	4.2	2.0	1.6	0.6	0.4	1.0
Nitrite as N, mg/l		16.4	20.5	22.0	2.8	4.0
Phosphate (total), mg/l	0.03					
Phosphate (ortho), mg/l	0.02	0.11	0.46	0.12	0.27	0.12
Calcium as Ca, mg/l	689					
Magnesium as Mg, mg/l	343					
Potassium as K, mg/l	180		174			
Sodium as Na, mg/l	1,470		3,920			
Aluminum as Al, μg/l			300			
Arsenic as As, μg/l			2.2			
Barium as Ba, μg/l			1,850			
Cadmium as Cd, μg/l			41			
Chromium as Cr, μg/l			42			
Copper as Cu, μg/l			11			
Iron as Fe, μg/l			180			
Lead as Pb, μg/l			188			
Manganese as Mn, μg/l			94			
Mercury as Hg, μg/l			0.40			
Molybdenum as Mo, μg/l			≤ 50			
Nickel as Ni, μg/l			84			
Selenium as Se, μg/l			0.65			
Silver as Ag, μg/l			18			
Zinc as Zn, μg/l			32			

Station no. 12, Upper Red Bluff Reservoir

Air temperature, C°		16	14			
Water temperature, C°		12	16			
Conductivity, 25°C/μmhos/cm	32,000	12,000	22,500	3,250	20,000	8,500
pH	8.09	7.6	7.9			
Turbidity	4.2	3	7	22	40	40
Total dissolved solids, mg/l	18,400					
Hardness as $CaCO_3$, mg/l	3,010	2,890	3,200	1,500	3,160	2,100
Dissolved oxygen, mg/l		12.4	8.4	8.4	8.1	8.5
Alkalinity as $CaCO_3$	111					
Bicarbonate as HCO_3, mg/l	135					
Chloride as Cl, mg/l	8,920	3,500	6,000	1,400	7,400	3,000
Sulfate as SO_4, mg/l	2,640	2,150	2,335	1,150	2,160	1,375
Ammonia as N, mg/l	0.038					
Nitrate as N, mg/l	2.69	1.2	1.2	2.0	0.7	0.6
Nitrite as N, mg/l		8.4	33.6	4.72	11.2	2.8

Station no. 12, continued	January	February	March	June	August	September
Phosphate (total), mg/l	0.049					
Phosphate (ortho), mg/l	0.005		0.44	0.27	1.84	0.08
Calcium as Ca, mg/l	709					
Magnesium as Mg, mg/l	302					
Potassium as K, mg/l	170		138			
Sodium as Na, mg/l	1,490		3,260			
Aluminum as Al, μg/l			150			
Arsenic as As, μg/l			1.5			
Barium as Ba, μg/l			1.3			
Cadmium as Cd, μg/l			34			
Chromium as Cr, μg/l			10			
Copper as Cu, μg/l			10			
Iron as Fe, μg/l			222			
Lead as Pb, μg/l			211			
Manganese as Mn, μg/l			110			
Mercury as Hg, μg/l			0.57			
Molybdenum as Mo, μg/l			≤50			
Nickel as Ni, μg/l			203			
Selenium as Se, μg/l			≤0.30			
Silver as Ag, μg/l			8.3			
Zinc as Zn, μg/l			27			

Station no. 13, Lower Red Bluff Reservoir

Air temperature, C°		19	28			
Water temperature, C°		10	21			
Conductivity, 25°/μmhos/cm		12,000	23,750	5,000	18,000	12,000
pH		8	7.7			
Turbidity		14	3	16	18	14
Total dissolved solids, mg/l@180°C		13,205				
Hardness as $CaCO_3$, mg/l		3,220	3,300	2,320	3,080	3,100
Dissolved oxygen, mg/l		13.2	9.8	8.4	7.0	8.7
Chloride as Cl, mg/l		5,450	7,000	2,300	4,600	4,800
Sulfate as SO_4, mg/l		2,600	2,750	1,825	2,272.5	2,000
Nitrate as N, mg/l			1.0	3.2	1.2	2.2
Nitrite as N, mg/l			17.4	34.8	2.8	6.8
Phosphate (ortho), mg/l			0.30	0.78	1.84	0.50
Calcium as Ca, mg/l		795				
Fluoride as F mg/l		1.1				
Magnesium as Mg, mg/l		300				
Potassium as K, mg/l		96	101			
Sodium as Na, mg/l		2,850	3,000			
Aluminum as A, μg/l		≤100	≤100			
Arsenic as As, μg/l		17	2			
Barium as Ba, μg/l		770	270			
Cadmium as Cd, μg/l		33	26			
Chromium as Cr, μg/l		14	30			
Copper as Cu, μg/l		12	8			
Iron as Fe, μg/l		90	151			
Lead as Pb, μg/l		205	140			
Manganese as Mn, μg/l		57	66			
Mercury as Hg, μg/l		0.60	0.76			
Molybdenum as Mo, μg/l		≤50	≤50			
Nickel as Ni, μg/l		34	42			
Selenium as Se, μg/l		≤0.5	≤0.3			
Silver as Ag, μg/l		10	4.8			
Zinc as Zn, μg/l		28	27			

Samples taken in March were analyzed by the Environmental Analysis Laboratory, Brigham Young University.

MEAN NUMBERS (m^{-2}) OF TOTAL BENTHIC ORGANISMS BY STATION AND DATE*
1978

Station	January 3-5	January 19-20	March 21-24	May 19-22	June 1-3
3, Hill Tank	293,453	29,904			
5, Pupfish Spring	1,722	5,167	55,763	236,[illegible]	
6, Pecos River at 6 Mile Dam		26,[illegible]			
7, Pecos River at 10 Mile Dam	[illegible],408		38,133	209,5[illegible]	
8, Harroun Canal				1,[illegible]	
9, Pecos River at Harroun Crossing	59,119		12,852	11,[illegible]	[illegible]
10, Pecos River at Malaga Bend				8,9[illegible]	[illegible]
11, Pecos River at El Paso Natural Gas Pipeline Crossing	17,431		134,[illegible]	[illegible]	
12, Upper Red Bluff Reservoir	235,459		98,349	55,383	
13, Lower Red Bluff Reservoir	773	14,[illegible]			[illegible]

MEAN NUMBERS (m^{-2}) OF BENTHIC ORGANISMS BY STATION AND DATE*
1978

Station 3, Hill Tank	January 3-5	January 19-22	March 20-24	May 19-23	May [illegible]	June 2-3
Oligochaeta	3,359(1)	1,184(2)				
Crustacea						
Amphipoda	86(1)					
Copepoda	106,401(1)					
Ostracoda	141,969(1)					
Insecta						
Hemiptera						
Corixidae	86(1)	732(2)				
Coleoptera		86(2)				
Diptera						
Ceratopogonidae	3,402(1)	15,588(2)				
Chironomidae	34,017(1)	8,805(2)				
Dolichopodidae	43(1)					
Acari	904(1)	172(2)				
Mollusca						
Sphaerium	3,186(1)	3,337(2)				
TOTAL	293,453	29,904				
Station 5, Pupfish Springs						
Nematoda	86(1)		172(2)			
Oligochaeta			366(2)	172(1)		
Crustacea						
Amphipoda	86(1)					
Insecta						
Diptera						
Ceratopogonidae	1,206(1)	1,565(3)	53,674(2)	235,323(1)		

Station 5, continued	January 3-5	January 19-22	March 20-24	May 19-23	May 30	June 2-3
Chironomidae		29(3)				
Dolichopodidae	344(1)	28(3)				
Ephydridae		3,502(3)	689(2)	344(1)		
Stratiomyidae		43(3)	882(2)	387(1)		
TOTAL	1,722	3,167	55,783	236,226		
Station 6, Pecos River at 6 Mile Dam						
Nematoda		23(2)				
Oligochaeta		629(2)				
Crustacea						
Amphipoda		16(2)				
Insecta						
Collembola		5(2)				
Coleoptera						
Hydrophilidae		37(2)				
Diptera						
Ceratopogonidae		720(2)				
Chironomidae		1,872(2)				
Dolichopodidae		32(2)				
Muscidae		5(2)				
Psychodidae		10(2)				
Simuliidae		22,865(2)				
Tabanidae		5(2)				
Acari		37(2)				
Mollusca		192(2)				
TOTAL		26,448				
Station 7, Pecos River at 10 Mile Dam						
Nematoda	3,648(1)		2,561(2)		4,099(1)	
Oligochaeta	1,818(1)		28,734(2)		32,086(1)	
Hirudinea	11(1)					
Crustacea						
Amphipoda	36,057(1)		1,700(2)		99,820(1)	
Insecta						
Ephemeroptera	11(1)		11(2)			
Odonata						
Zygoptera	118(1)					
Hemiptera						
Corixidae					129(1)	
Coleoptera						
Dytiscidae	75(1)					
Hydrophilidae	387(1)		462(2)		269(1)	
Unidentified	11(1)		64(2)			
Diptera						
Ceratopogonidae	538(1)		446(2)		699(1)	
Chironomidae	3,637(1)		13,138(2)			
Muscidae	11(1)					
Psychodidae	11(1)					
Simuliidae			1,027(2)			
Stratiomyidae	11(1)					
Tabanidae	11(1)					
Mollusca	54(1)				62,085(1)	
TOTAL	46,409		48,143		199,187	

Station 9, Pecos River at Harroun Crossing

	January		March	May		June
	3-5	19-22	20-24	19-23	30	2-3
Nematoda	296(2)		224(2)	775(1)		189(1)
Oligochaeta	9,748(2)		2,252(2)	2,625(1)		34(1)
Hirudinea	5(2)					
Crustacea						
Amphipoda	70(2)		14(2)			103(1)
Insecta						
Collembola	5(2)					
Ephemeroptera	21(2)		87(1)			516(1)
Odonata						
Zygoptera	280(2)		16(2)			
Coleoptera						
Dryopidae	204(2)		19(2)	129(1)		17(1)
Hydrophilidae	27(2)		24(2)	86(1)		
Unidentified	27(2)					
Trichoptera						
Cheumatopsyche	64,361(2)		2,618(2)	2,238(1)		344(1)
Icthytrichia	349(2)		1,447(2)	215(1)		17(1)
Hydropsyche	26(2)		14(2)			
Hydroptila	107(2)		41(2)	43(1)		
Lepidoptera						
Pyralidae	774(2)		251(2)	43(1)		
Diptera						
Ceratopogonidae	26(2)		100(2)			17(1)
Chironomidae	12,164(2)		5,593(2)	5,208(1)		3,479(1)
Simuliidae	5(2)					
Tabanidae	5(2)		5(2)			
Acari	11(2)		14(2)			
Mollusca						
Physa	608(2)		133(2)	215(1)		
TOTAL	89,119		12,852	11,577		4,716

Station 11, Pecos River at El Paso Natural Gas Pipeline Crossing

Foraminifera		3,906(1)	
Nematoda	17,087(1)	120,243(1)	38,865(1)
Oligochaeta	172(1)	269(1)	301(1)
Insecta			
Coleoptera			
Hydrophilidae			129(1)
Diptera			
Ceratopogonidae	172(1)	377(1)	86(1)
Chironomidae			387(1)
TOTAL	17,431	124,795	39,768

Station 12, Upper Red Bluff Reservoir

Nematoda	209,056(2)	76,819(1)	41,294(1)
Oligochaeta	16,004(2)	19,205(1)	2,584(1)
Insecta			
Diptera			
Ceratopogonidae	3,531(2)	1,033(1)	517(1)
Chironomidae	6,868(2)	1,249(1)	9,990(1)
Mollusca		43	
TOTAL	235,459	98,349	54,385

Station 13, Lower Red Bluff Reservoir

Nematoda	150(2)	38,754(3)	495(2)
Oligochaeta	387(2)	531(3)	

Station 13, Lower Red Bluff Reservoir

	January		March	May		June
	3-5	19-22	20-24	19-23	30	2-3
Insecta						
Diptera						
Ceratopogonidae	86(2)					
Chironomidae	129(2)	2,038(3)				172(2)
Muscidae	21(2)					
TOTAL	773	41,323				667

Number in parenthesis represents the number of samples taken.

*Suggested trends only; statistical verification not yet obtained on all series (see discussion of step analysis for methodology).