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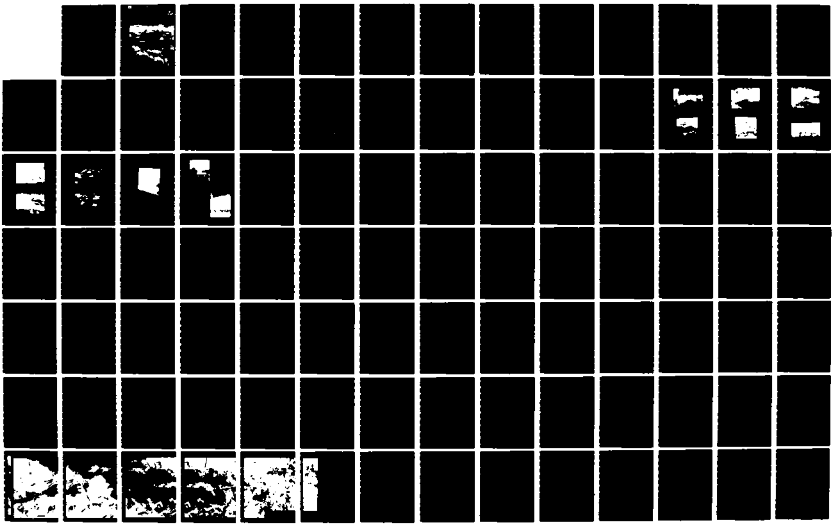

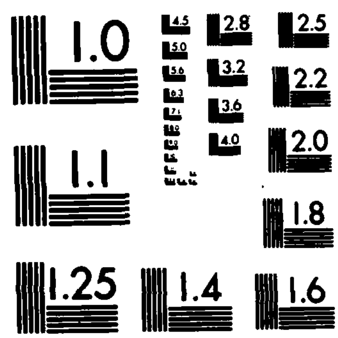

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The effect of blowsand reduction on the abundance of the fringe-toed lizard (Uma inornata) in the Coachella Valley, California

October 1981

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Densities of Uma inornata in ten 2.5-ha plots in the Coachella Valley were estimated by capture-recapture analysis during the spring and summer of 1980. Six of the ten plots were arranged in pairs, with one member of the pair in apparently undisturbed habitat upwind of a tamarisk windbreak and the other members downwind of the obstruction. The other four plots were in areas with sandy hummocks or mesquite dunes. The abundance of Uma varied in different plots ranging from as high as 45/ha^{-1} to zero. The three

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) plots downwind of tamarisk windbreaks where sand depletion and surface stabilization have been under way for a number of years were essentialy unoccupied by Uma. The upwind plots supported densities ranging from 11 to 45 ha^{-1}.

In general, variations in abundance of Uma were not statistically correlated with individual physical attributes of sand. By focusing on the quality of sand in dunes on the lee sides of shrubs we developed two models relating to densities of Uma ($\underline{N}$). Variables of interest were: penetrability of sand in lee areas ($\underline{P}$), surface coarseness ($\underline{C}$), diameter of sand grains at the 75th percentile of gradation by weight ($\underline{d}_{0.75}$), and years since surface stabilization ($\underline{Y}$). The multiple regression equation was:

$$\underline{N} = 3.7\underline{P} - 92.8\underline{d}_{0.75} - 4.8\underline{C} + 51.0$$

Years of stabilization ($\underline{Y}$) did not enter significantly into the equation. The other model derived from linear regression of Uma densities on a hybrid variable:

$$\underline{N} = 7.0 \left[\frac{\underline{P}}{C\underline{d}_{0.75} + 0.13\underline{Y}} \right] - 13.5$$

Both models explained about 81% of the observed variation in Uma densities. These models make some biological sense because sand penetrability is presumably a positive environmental factor and surface coarseness a negative one. It is also logical to assume that increasing surface stabilization is detrimental to Uma.

Methods of capture-recapture analysis used in this study sometimes resulted in unsatisfying upper bounds of confidence intervals for density estimates. further density estimates should be derived from analyses of a chain of at least three samples. Attempts to calibrate two shortcut methods of estimating numbers where not successful. Counts of Uma tracks did discriminate between a well-populated and an essentially unpopulated area. However, tracks of Uma and Callisaurus may be easily confused, and we do not believe track counts can be used as a reliable measure of relative densities. Counts of Uma in three areas under carefully limited conditions of temperature and wind were not correlated with capture-recapture estimates of numbers.

THE EFFECT OF BLOWSAND REDUCTION

ON THE ABUNDANCE OF THE FRINGE-TOED LIZARD

(UMA INORNATA) IN THE COACHELLA VALLEY, CALIFORNIA

A TWO - PART STUDY

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PART I

The Abundance of the Fringe-toed Lizard (*Uma inornata*) at 10 Sites in the Coachella Valley, California

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Abstract

Densities of *Uma inornata* in ten 2.25-ha plots in the Coachella Valley were estimated by capture-recapture analysis during the spring and summer of 1980. Six of the ten plots were arranged in pairs, with one member of the pair in apparently undisturbed habitat upwind of a tamarisk windbreak and the other member downwind of the obstruction. The other four plots were in areas with sandy hummocks or mesquite dunes. The abundance of *Uma* varied in different plots, ranging from as high as ~45 ha^{-1} to zero. The three plots downwind of tamarisk windbreaks where sand depletion and surface stabilization have been underway for a number of years were essentially unoccupied by *Uma*. The upwind plots supported densities ranging from 11 to 45 ha^{-1}.

In general, variations in abundance of *Uma* were not statistically correlated with individual physical attributes of sand. By focusing on the quality of sand in dunes on the lee sides of shrubs we developed two models relating to densities of *Uma* ($\underline{N}$). Variables of interest were: penetrability of sand in lee areas ($\underline{P}$), surface coarseness ($\underline{C}$), diameter of sand grains at the 75th percentile of gradation by weight ($\underline{d}_{0.75}$), and years since surface stabilization ($\underline{Y}$). The multiple regression equation was:

$$\underline{N} = 3.7\underline{P} - 92.8\underline{d}_{0.75} - 4.8\underline{C} + 51.0$$

Years of stabilization ($\underline{Y}$) did not enter significantly in the equation. The other model derived from linear regression of *Uma* densities on a hybrid variable:

$$\underline{N} = 7.0 \left[\frac{\underline{P}}{\underline{Cd}_{0.75} + 0.13\underline{Y}} \right] - 13.5$$

Both models explained about 81% of the observed variation in *Uma* densities. These models make some biological sense because sand penetrability is presumably a positive environmental factor and surface coarseness a negative one. It is also logical to assume that increasing surface stabilization is detrimental to *Uma*.

Methods of capture-recapture analysis used in this study sometimes resulted in unsatisfying upper bounds of confidence intervals for density estimates. Future density estimates should be derived from analyses of a chain of at least three samples. Attempts to calibrate two short-cut methods of estimating numbers were not successful. Counts of *Uma* tracks did discriminate between a well-populated and an essentially unpopulated area. However, tracks of *Uma* and *Callisaurus* may be easily confused, and we do not believe track counts can be used as a reliable measure of relative densities. Counts of *Uma* in three areas under carefully limited conditions of temperature and wind were not correlated with capture-recapture estimates of numbers.

Introduction

The Coachella Valley fringe-toed lizard (Uma inornata) is restricted to windblown sand deposits in the Coachella Valley, Riverside County, from Cabazon in San Gorgonio Pass to near Thermal in the southern end of the valley. According to England and Nelson (1976), the historical range of the species was about 324 mi^2, which probably included some 200 mi^2 of suitable habitat (A. S. England, pers. comm.). In 1979, it was estimated that only about 99 mi^2 pf suitable habitat remained (A. S. England, pers. comm.). The United States Fish and Wildlife Service proposed listing Uma inornata as a Threatened Species in 1978, but was forced to withdraw the proposed Critical Habitat because of amendments to the Endangered Species Act (Federal Register, 1980). However, the USFWS in September, 1980 listed Uma inornata as a Threatened Species and designated its Critical Habitat. Uma inornata was declared an Endangered Species by the State of California in June 1980.

The status of this species and the protection of at least some of its remaining habitat are clearly critical environmental issues. Actions by federal or state agencies, or by private corporations, impinging on areas inhabited by Uma inornata must be carefully evaluated, both in terms of immediate and long-term ecological consequences.

Proposed flood control projects by the Corps of Engineers in Riverside County raise questions of this nature (U. S. Corps of Engineers, 1979). For example, flood control plans under consideration could result in a near 50% or greater reduction of windblown sand entering the Coachella Valley from the west. With incorporated sand control measures this reduction could be increased to near 100%. The presumed consequence of such immobilization of source sand would be a gradual elimination of existing sand from the alluvial valley floor from Indian Avenue to Vista Chino Road at a rate of about 0.75 mile per year (Weaver 1979). Beyond Vista Chino Road hummocks would gradually be depleted and the intervening sand areas would become stabilized. In essence, movement of sand by wind would gradually diminish to zero. This effect would progress to the southeast at around 0.25 mile per year beyond Vista Chino Road. Weaver (1979) has estimated that it might take 20 years for this depletion and stabilization of sand to reach Ramon Road.

Because _Uma inornata_ is restricted to aeolian sand deposits, environmental changes of this nature could be extremely deleterious to the lizard. It is possible to test the effects of sand depletion and stabilization on a small scale by examining effects of existing windbreaks. These obstructions act as barriers to the natural transport of sand. Tamarisk trees have been planted in various portions of the Coachella Valley to impede the flow of sand. Such windbreaks reduce wind velocity and lead to deposition of sand around the impediments. The interruption of flow produces, beyond the area directly shielded from natural wind conditions, an area with gradually reduced sand deposits and an increasingly stabilized surface. Some insight as to effects of sand depletion and surface stabilization, by whatever mechanism, may be gained by contrasting the status of _Uma inornata_ in areas upwind and downwind of obstructions. Areas should be selected with the assurance that they were identical before the obstruction was established. One purpose of the work hereinafter described is to compare the abundance of _Uma_ in such paired areas. We need to know more about the local distribution of _Uma inornata_, its relative abundance in different types of habitats, and how differences in numbers are related to physical and biological attributes of the lizard's environment. Methods of estimating the abundance of Uma, both directly and indirectly, should be explored (England and Nelson 1976).

A brief study of Uma inornata in the Coachella Valley was planned during the early spring of 1980. Six areas (three pairs) were identified, with members of each pair separated by an obstruction to sand flow. In addition to these areas, four others were selected representative of what England and Nelson (1976) termed "sandy hummocks" and "mesquite dunes." We attempted to estimate densities of Uma inornata in all areas by capture-recapture analysis, and tested two indirect methods of assessing abundance of this species.

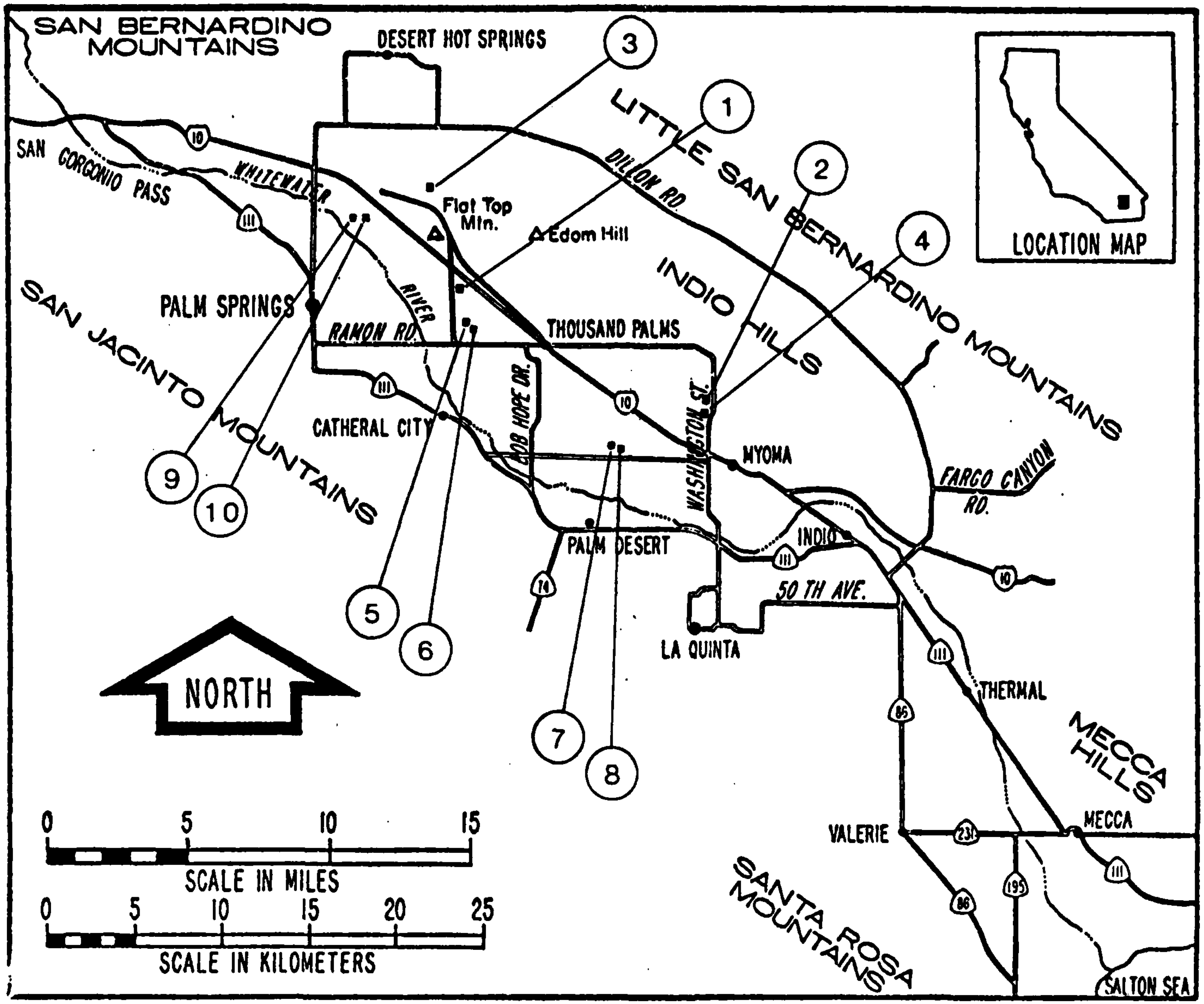
Procedures

Locations for 10 study sites in the Coachella Valley were established on April 2, 1980, following an inspection of prospective sites by Russell Duncan, Sid England, James Rorabaugh, Fred Turner and Donald Weaver. Rorabaugh and Duncan began field work on April 3. Jon Walters joined the group on May 1, and field work concluded on June 20, 1980. Each study area was a square 150 m on a side (2.25 ha) and staked at 25 m intervals. Up to seven days were devoted to plots, unless early efforts gave clear evidence that no Uma were present in the area.

Plots 5 and 6, 7 and 8, and 9 and 10 were paired plots. The first member of each pair was an apparently undisturbed area where it appeared that Uma inornata would be present. The second member of each pair was an area downwind of the undisturbed area, and lying leeward of tamarisk trees. Each downwind area was far enough from the obstruction to be exposed to natural wind conditions. Plots 1-4 were not a part of this experimental scheme, but were representative of mesquite dunes and sandy hummocks, as defined by England and Nelson (1976). All plots lay within ∿2 miles of Interstate 10 between Garnet (ca. 6 miles n. Palm Springs) and Myoma (ca. 5 miles nw. Indio). Exhibit 1 shows location of plots and Table 1 summarizes further information.

The downwind member of each of the three pairs of plots was carefully positioned by Weaver so that it generally lay along the path of prevailing sand transport. Historically, these lee areas were exposed to the same sand fluxes occurring in the undisturbed plots. Plots 1 and 2 were representative of "sandy hummocks" habitat; Plots 3 and 4 of "mesquite dunes" (England and Nelson 1976). In fact, Plot 1 included one of the study areas used by England and Nelson.

Both Norris (1958) and Pough (1970) have emphasized the importance of sand grain size as it affects the local occurrence of *Uma*. Soils with high proportions of very small silty particles have generally been considered unsuitable, and coarse soils with high percentages of particles >1 mm in diameter are also inhibitory. Because the local distribution of *Uma* is so closely linked with availability of suitable substrates, the physical makeup of sands in the ten study plots was evaluated. This work was done by Weaver, and is fully reported elsewhere (Weaver 1980). All plots were photographed during the spring of 1980, and sampling and testing carried out at locations representative of i) windward and ii) lee sides of sand deposits caused by trees or shrubs, iii) typical sandy substrates in the open, and iv) the coarsest substrates in the open. Relative extents (%) of these four micro-environments were estimated for each plot. Particle size distributions



Exh. 1. Locations of ten sites used in a study of Uma inornata in the Coachella Valley, California.

Table 1. Locations of ten plots used in studies of *Uma inornata* in the Coachella Valley in 1980. Habitat types (SH: sandy hummocks, MD: mesquite dunes, SP: sandy plains) are designated according to England and Nelson (1976).

Plot	Habitat type	Location
1	SH	Date Palm Drive and Los Gatos Road, 5 miles e. Palm Springs
2	SH	Washington Street, 1.9 miles n. I-10
3	MD	Varner Road and Mountain View Drive, 6 miles ne. Palm Springs
4	MD	Washington Street, 1.2 miles n. I-10
5	SP	Ramon Road and DaVall Road, 6 miles e. Palm Springs
6	-	same area, but downwind of tamarisk windbreak
7	SP	Country Club Drive and Cook Street, 4 miles w. Myoma
8	-	same area, but downwind of tamarisk windbreak
9	SH	south of I-10 and Southern Pacific Railroad, 1.5 miles se. Garnet
10	-	same area, but north of the railroad and downwind of tamarisk windbreak

were determined for all sand samples. Other measurements included penetrability, crustiness, surface coarseness, surface stabilization, mean and median diameters of sand grains and sorting coefficients. Full procedural details are given by Weaver (1980).

In Plot 7, Uma were captured, marked and released on April 7, 9, 11 and 15. Lizards were marked by toe-clipping and with quick-drying model airplane paint. All records for this area were based on animals actually caught and examined. Capture-recapture data were analyzed as a chain of four samples (Schumacher and Eschmeyer 1943). The 95% confidence range for the population estimate was computed as given by DeLury (1958).

In Plots 1, 2, 3, 4, 5 and 9, Uma were captured over periods of 4 to 5 days. Captured animals were marked with paint. Captures of new individuals were made more efficient because no effort was expended in recapturing animals already marked. On the last day of work in each of these areas, a series of 6-8 separate censuses was carried out. Workers walked slowly and systematically through a plot, recording numbers of marked (painted) and unmarked lizards. After the area had been traversed, the procedure was repeated with 15-minute waits between individual censuses. This system provided from 6-8 separate censuses from which numbers of Uma could be estimated. If a was the number of marked lizards at risk after the period of marking, n_i was the total number of lizards seen during the i_{th} census, and r_i was the number of painted lizards observed during the i_{th} census, then:

$$\hat{N}_i = a(n_i+1)/(r_i+1) \qquad (1)$$

This is the Lincoln Index, with corrections for bias (Bailey 1952).

We estimated confidence intervals for these estimates in two ways. First, we simply computed the standard deviations ($\underline{s}$) of population estimates obtained for various plots in the final day of censuses. Then we estimated the 95% confidence interval as $\pm 1.96\underline{s}$. Second, we computed the variances of the various $\underline{N}_i$ for a given plot, as suggested by Bailey (1952):

$$\mathrm{Var}(\hat{N}_i) = a^2(n_i+1)(n_i-r_i)/(r_i+1)^2(r_i+2) \qquad (2)$$

We could then compute the mean variances associated with the mean population estimates for each area. Standard deviations calculated from these variances were used as above. Upper limits of populations in plots were based on the higher of the two estimates of standard deviations. Lower limits of populations computed by either method were always less than numbers of different _Uma_ marked in areas. So we defined lower limits of these populations as the number of different _Uma_ registered. If no _Uma_ were observed in an area (Plots 6, 10), or if _Uma_ were marked and no unmarked individuals were taken in subsequent censuses (Plots 5, 8), we estimated the abundance of _Uma_ as zero or as the number of different _Uma_ marked.

We attempted to count tracks of _Uma_ in Plots 7 and 8, as described by England and Nelson (1976). Eight 50 x 1/2 m lanes, distributed regularly within plots, were established early in the morning--before _Uma_ were active. The lanes were examined late in the afternoon after activity had ceased. Numbers of _Uma_ track crossings were recorded for each of the lanes for four days in each plot. Because of variability in vegetative cover and substrate, which influenced effects of wind, lanes varied in their susceptibility to tracking and in the persistence of tracks. We estimated percentages of lanes suitable for the procedure.

We also tested another measure of relative abundance: numbers of Uma observed per man-hour under standardized conditions of temperature and wind. Uma were active when air temperatures (1 m above ground surface) were between 22 and 39° C and ground surface temperatures between 37 and 58° C. Observations were made on windless or nearly windless days. Light to moderate breezes caused movements of bushes which made it more difficult to see and hear Uma. Counts were made in Plots 2, 4 and 7 between June 18 and 20. A count was conducted by one observer making an hour-long sweep of a plot. Observers did not dig in, or disturb the sand in any way, so only lizards on the surface were counted. Each plot was examined by three different observers on six different occasions, so each plot was inspected for 18 man-hours.

Qualitative assessments of vegetation in each plot were made by Russell Duncan.

Results

General aspects of the ten study areas are illustrated in Figures 1-13. Weaver (1980) has summarized the sources of sand found in these areas, the past and present rates at which aeolian sand is received in plots, and the physical attributes of substrates and sand particles in plots. Sand from the Whitewater River flood plain is blown into the northwestern portion of the Coachella Valley and is swept down the valley. This is the source sand for Plots 1 and 5-10. The sand in Plots 2 and 4 is from the Indio Hills, that in Plot 3 from the Mission and Morongo Creek washes. Direction of sand movement is roughly from the northwest across all plots but 3, 9 and 10. In these three plots sand comes from a more westerly vector.

Because of sand source locations and gradual diminution of wind velocity down the Coachella Valley, rates at which sand passes across plots is highest towards the western end of the valley. For example, the historical mean annual rate of passage in Plots 9 and 10 has been around 20 yd^3 per foot-wide path. In Plot 1 it is around 11.5 yd^3 per foot-wide path, diminishing to about 6-7 yd^3 in Plots 5-8. Plots 2, 3 and 4 are exposed to only 1-2 yd^3 per year per foot-wide path. Because of windbreaks protecting Plots 6, 8 and 10, present mean annual rates of sand reception are zero (Weaver 1980).

About 90% of Plot 10 was non-sandy, and the ensuing discussion pertains only to Plots 1-9. From 20-30% of Plots 1 and 2 were non-sandy, but from 95-100% of the other seven plots was sandy. Areas of coarse substrates ranged from 10-20%. In most plots, open areas of

Fig. 1. Plot 1.

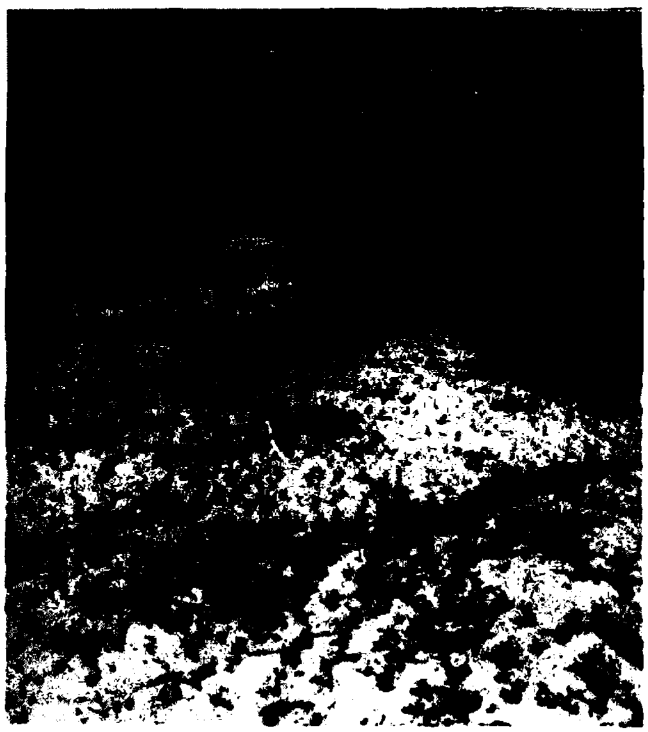


Fig. 2. Plot 2.

Fig. 3. Plot 3.

Fig. 4. Plot 4.

Fig. 5. Plot 5.

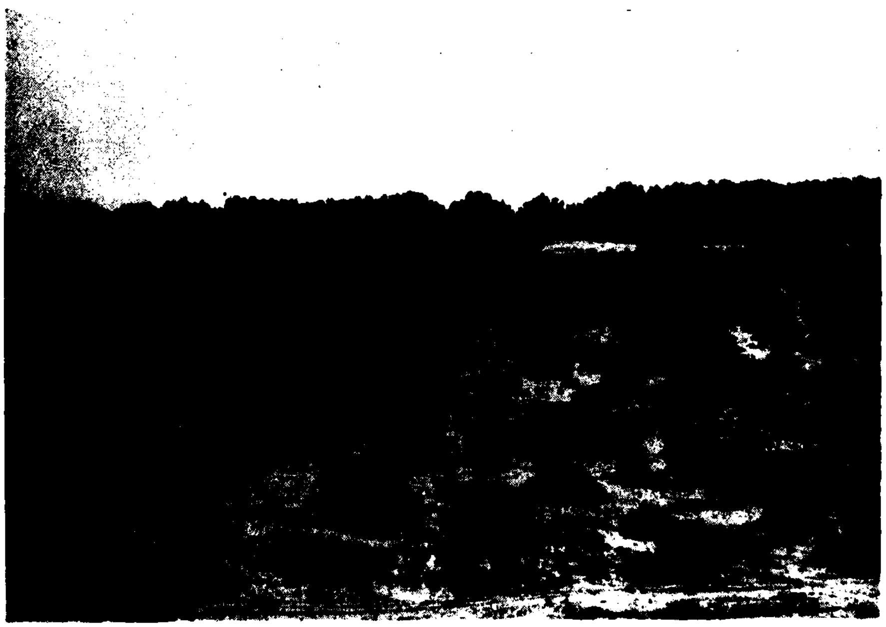


Fig. 6. Plot 6.

Fig. 7. Plot 7.

Fig. 8. Plot 8.

Fig. 9. Plot 9.

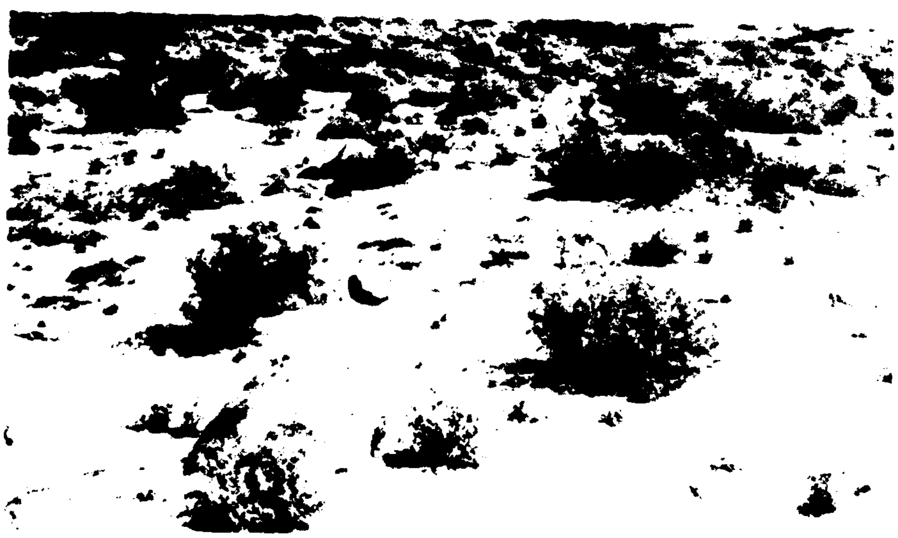


Fig. 10. Plot 10.

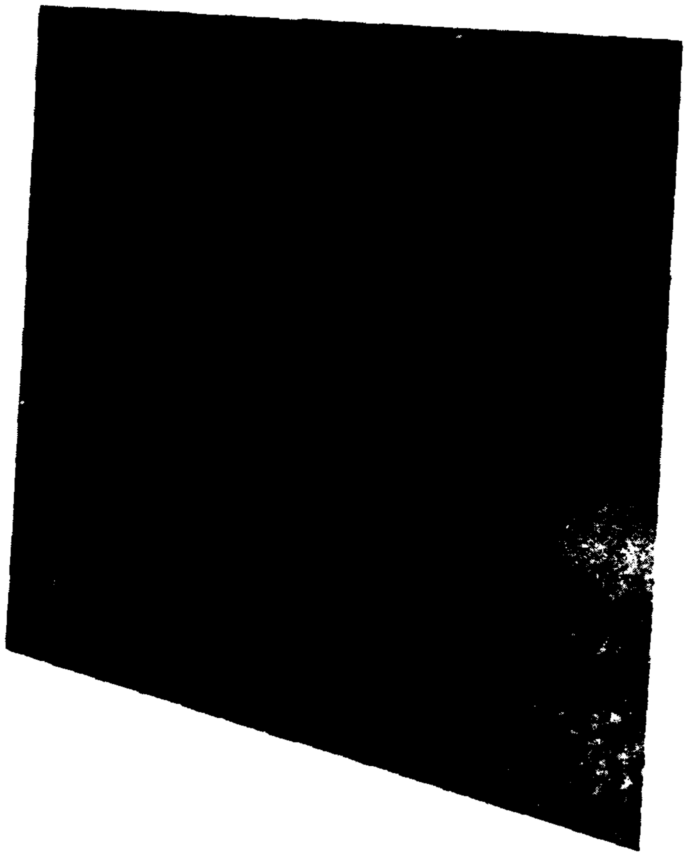


Fig. 11. General locales of Plots 5 (upper left) and 6 (lower right before establishment of windbreaks.

Fig. 12. General locales of Plots 7 (left) and 8 (right) before establishment of windbreaks.

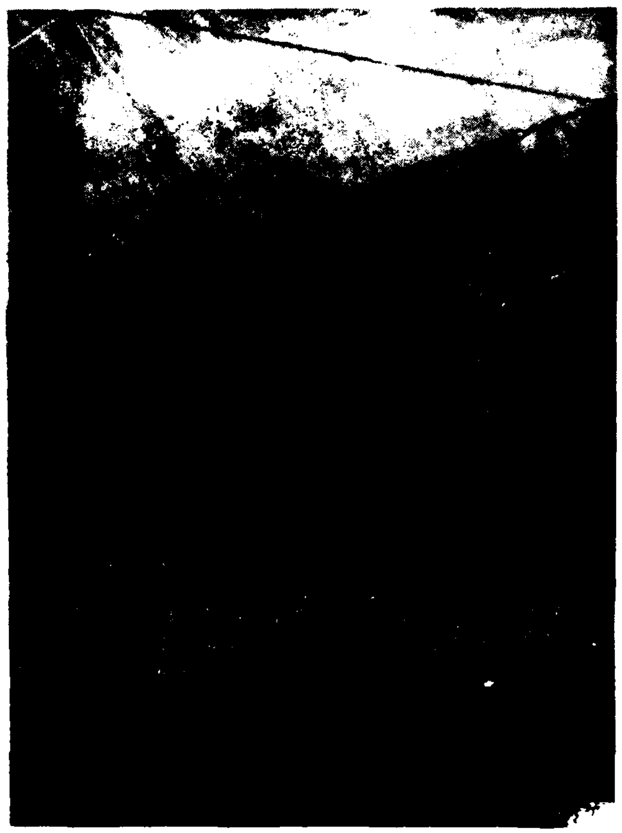


Fig. 13. General locales of Plots 9 (lower left) and 10 (upper right) before establishment of windbreaks.

typical sand made up from 35-80% of the area, but only 15-25% of Plots 1, 3 and 4 were of this nature. Because varying proportions of plots were composed of different sorts of microhabitats, Weaver computed weighted means for most variables. Table 2 summarizes attributes of sand in plots. Plot 10 clearly differed from all other plots. It has been 17 years since new sand entered the area. The soil surface is extremely stabilized against further wind erosion and is relatively impenetrable. Over 40% (by weight) of soil particles are <0.1 mm or >1.0 mm in diameter.

Burrows of undetermined origin existed on all sites. Weaver (1980) indicated that near-surface crustiness of sand deposits and substrates is presently greater than normal at all sites because of abnormally high rainfall between 1976 and 1980. This condition reduces ease of penetrability, but enhances sand cohesion and the persistence of burrows.

In all plots, 103 male and 89 female _Uma inornata_ were registered during the spring and summer of 1980. These numbers do not differ significantly from those expected assuming a sex ratio of 1:1 ($X^2 = 1.0$, $p = \sim 0.3$). Mean snout-vent lengths of 44 females measured in Plots 1, 4, 5 and 9 ranged from 67.4 mm (Plot 9) to 78.8 mm (Plot 1). Mean snout-vent lengths of 61 males in these same plots ranged from 82.8 mm (Plot 4) to 104.7 mm (Plot 5). Turner et al. (1978) reported mean snout-vent lengths of _Uma_ in a plot on Washington Street as 75.4 mm for 15 females, 90.6 mm for 16 males. Body sizes of males are more variable than those of females, and males up to 121 mm in snout-vent length

Table 2. Attributes of sand in 10 study areas in the Coachella Valley, Riverside County, California. All but "Years of stabilization" and "Surface coarseness" are weighted means based on varying amounts of four different microhabitats in plots.

Plot	Years of stabilization	Mean grain size diameter (mm)	Percent (by weight) less than 0.1 mm diameter	Percent (by weight) more than 1.0 mm diameter	Penetrability index (1 ft)	Surface coarseness (diameter of coarsest surface grains in plot, mm)
1	4	0.33	7.6	6.1	7.80	3.00
2	4	0.29	10.6	1.3	5.72	1.66
3	0	0.28	8.6	2.0	7.44	3.26
4	4	0.18	13.7	0	6.24	1.36
5	4	0.38	12.0	19.9	6.31	3.10
6	7	0.29	13.4	9.0	6.89	3.18
7	4	0.32	9.6	3.1	6.83	2.08
8	12	0.31	12.3	3.6	6.84	2.18
9	0	0.32	9.3	10.6	6.35	2.86
10	17	0.29	22.3	19.4	4.73	8.00

were recorded. With small samples, mean sizes can be significantly influenced by a few very large males.

Three of the ten plots examined (6, 8 and 10) were either unoccupied or very sparsely populated by Uma inornata. In the course of 20 man-hours of work under favorable weather conditions one Uma was captured in Plot 8. Twenty man-hours of work were expended in each of Plots 6 and 10, but no Uma were observed. Lizard sampling data from the other plots are given in Appendixes 1-7.

Table 3 summarizes experience in all ten plots and includes data from Plot 17 (on Washington Street), which was examined in 1978 (Turner et al. 1978). One 112 mm male marked in Plot 1 had been previously marked (Number 41) by England in 1979 (A.S. England, pers. comm.). We also encountered two other marked males in Plot 1 but could not reconcile these records with any of England's earlier observations.

The most important feature of the observations set forth in Table 3 is the contrast between the paired plots. In all instances the plots upwind of tamarisk windbreaks (5, 7 and 9) sustained populations of Uma (in two cases, fairly high densities) while downwind plots were sparsely inhabited (Plot 8) or uninhabited (Plots 6, 10). Figures 11-13 illustrate aerial views of these three areas before tamarisk trees were planted, and show that the paired habitats were originally alike. Today, however, the downwind plots are less sandy--particularly Plot 10. A preliminary inspection of this plot on April 2 suggested that it was not suitable Uma habitat and subsequent observations bore this out.

To what extent can the estimated densities of Uma (Table 3) be understood in terms of the sand characteristics given in Table 2?

Table 3. Estimates of density of *Uma inornata* in 11 plots in the Coachella Valley, Riverside County, California, in 1980

Plot	Different *Uma* caught	*Uma* per man-hour	Population estimate (2.25 ha)	Maximum numbers (1)	Maximum numbers (2)	Density estimate ($n \cdot ha^{-1}$)	Confidence range for density estimate ($n \cdot ha^{-1}$)
1	30	0.63	38.8	51	54	17.2	13.3-24.1
2	25	0.57	37.7	58	56	16.8	11.1-25.1
3	10	0.20	19.9	30	40	8.8	4.4-17.0
4	43	0.70	102.4	186	189	45.5	19.1-84.0
5	10	0.56	10.0	10	10	4.4	
6	0	0	0			0	
7	38	1.12	96.7			43.0	39.1-47.6[2]
8	1	0.04	1			0.4	
9	35	0.98	101.3	183	217	45.0	15.6-96.2
10	0	0	0			0	
17(1978)	31		46.7[1]			10.6	9.3-12.2[2]

[1] 4.41 ha

[2] Schumacher-Eschmeyer method

Table 4 gives the correlation matrix for these variables. The abundance of _Uma_ is not significantly correlated with any of these variables, and non-parametric rank correlation tests (Snedecor 1956: 190) give the same results. Although high proportions of very small (<0.1 mm) or coarse (>1.0 mm) sand grains have been found to inhibit burrowing by _Uma_ (Norris 1958, Pough 1970), these measures were of little use in understanding the densities of _Uma_ in Plots 1-9. In fact, when _Uma_ densities were regressed on 32 other variables, based on sand measurements in different microenvironments in plots, only two significant correlations emerged (Appendix 8). Densities were positively correlated with surface crustiness in deposits on windward sides of shrubs and negatively correlated with amounts of sand coarser than 1.0 mm in deposits leeward of shrubs. In general, then, observed densities of _Uma_ were statistically uncorrelated with the individual sand variables we measured.

The six independent variables in Table 2 were next used in multiple regression analysis using Biomed Program BMDO2R (Dixon 1971). Five variables entered (all but surface coarseness), giving a multiple R of 0.74. This explains only about 55% of the observed variation in the dependent variable.

Uma often burrow in dunes on the lee sides of shrubs. Stebbins (1944: 330) stated: "Where barchanes, dunes or hummocks abound, the lizards are seldom...on the windward side but rather occur more commonly toward the base of the more precipitous lee side of such deposits." Norris (1958) also commented on the selection of the leeward sides of shrubs by _Uma_--both for basking and burrowing. Both authors emphasized the finer grain size of lee sands relative to those on the windward sides

Table 4. Correlation matrix for _Uma_ density and sand variables in 10 plots in the Coachella Valley, Riverside County, California.

	Years of stabilization	Penetrability	Mean grain size	% <0.1 mm	% >1.0 mm	Surface coarseness
Uma density	-0.551	0.064	-0.339	-0.374	-0.411	-0.475
Years since stabilization	-	-0.547	-0.027	0.849	0.403	0.653
Penetrability	-	-	0.163	-0.798	-0.465	-0.526
Mean grain size, mm	-	-	-	-0.244	0.552	0.156
% <0.1 mm	-	-	-	-	0.535	0.745
% >1.0 mm	-	-	-	-	-	0.721

of hummocks. We next considered attributes of sand in the lee of shrubs or trees in the Coachella Valley plots. Variables selected for consideration were: surface penetrability ($\underline{P}$), sand grain diameter at the 75th percentile of gradation by weight ($\underline{d}_{0.75}$), % of sand grains <0.1 mm in diameter ($\underline{p}_1$), and % of grains >1.0 mm in diameter ($\underline{p}_2$). Values for lee sand variables are given in Table 5. These variables were used together with years of stabilization ($\underline{Y}$) and surface coarseness ($\underline{C}$) in another multiple regression analysis (Table 6). The first three variables entered were $\text{diameter}_{0.75}$, surface coarseness and penetrability. These variables produced a multiple $\underline{R}$ of 0.90 ($\underline{R}^2$ = 0.81). None of the other variables had much effect on the value of $\underline{R}$. The three-variable model for predicting *Uma* density ($\underline{N}$) was:

$$\underline{N} = 3.7\underline{P} - 92.8\underline{d}_{0.75} - 4.8\underline{C} + 51.0 \qquad (3)$$

We also computed a model with these three variables and a forced zero-intercept:

$$\underline{N} = 8.3\underline{P} - 66.2\underline{d}_{0.75} - 3.1\underline{C} \qquad (4)$$

An alternative approach is to combine four of the variables used in these analyses into one hybrid variable:

$$\frac{\underline{P}}{(\underline{C}\underline{d}_{0.75}) + 0.13\underline{Y}} \qquad (5)$$

Table 5. Measures of penetrability, percent of sand grains <0.1 mm, percent of sand grains >1.0 mm, and grain size at the 75th percentile of gradation by weight based on measurements of lee sands in ten plots in the Coachella Valley.

Plot	Penetrability (1 foot drop, mm)	% <0.1 mm	% >1.0 mm	$Diameter_{0.75}$ (mm)
1	9.07	9	3	0.52
2	5.23	10	2	0.53
3	7.70	7	1	0.45
4	6.97	14	0	0.18
5	6.43	10	4	0.54
6	6.93	14	3	0.64
7	8.80	8	3	0.47
8	5.70	6	3	0.66
9	7.07	8	0	0.33
10	5.63	18	6	0.38

Table 6. Results of multiple regression analysis involving estimated densities of *Uma inornata* in 10 plots in the Coachella Valley and six sand variables.

Variables entered	Multiple *R*	Multiple R^2	*F*-value to enter
Sand grain diameter at 75th percentile (mm), lee sand	0.695	0.483	7.48
Surface coarseness	0.868	0.754	7.70
Penetrability, lee	0.900	0.811	1.79
Percent of sand >1.0 mm in diameter, lee	0.903	0.815	0.10
Years of stabilization	0.905	0.819	0.10
Percent of sand <0.1 mm in diameter, lee	0.911	0.830	0.18

When *Uma* densities were regressed on this variable r = 0.90, explaining about the same amount of variation in the dependent variable as the multiple regression model. The resulting equation was:

$$\underline{N} = 7.0 \left[\frac{\underline{P}}{\underline{Cd}_{0.75} + 0.13\underline{Y}} \right] - 13.5 \qquad (6)$$

These models make some biological sense, because sand penetrability is presumably a positive environmental factor and surface coarseness a negative one. Equation (6) also incorporates the expected negative effect of increasing years of stabilization. When considered in conjunction with other variables, sand grain diameters at the 75th percentile of gradation by weight were found to be the single size gradation parameter most closely associated with observed *Uma* densities. While it is reasonable to expect that *Uma* densities are influenced by sand size gradation, it is not clear why they should be sensitive to grain diameters at that particular percentile.

Observations ($\underline{y}_i$) and predictions ($\hat{\underline{y}}_i$) by these three models (Equations 3, 4 and 6) are given in Table 7. How well the models fit the observations may be compared as suggested by Fraleigh (1978). If $\bar{\underline{y}}$ is the mean of observations, one computes $\Sigma(\underline{y}_i - \bar{\underline{y}})^2$ or MS_T, and $\Sigma(\underline{y}_i - \underline{y}_i)^2$, or MS_E. The relative magnitude of these values is a measure of fit. If MS_E/MS_T is greater than one the model predictions do not "fit" observations as well as a straight line drawn through the mean of the observations. The value of MS_E/MS_T for predictions based on Equation (3) is 0.19, for predictions based on Equation (4) 0.31, and for predictions

Table 7. Observed densities ($n \cdot ha^{-1}$) of _Uma inornata_ in 10 plots in the Coachella Valley and densities predicted by three models.

Plot	Observed density	Density predicted by Equation (3)	Density predicted by Equation (4)	Density predicted by Equation (6)
1	17.2	21.6	31.6	17.0
2	16.8	13.0	3.2	12.6
3	8.8	21.8	24.0	23.1
4	45.5	53.3	41.7	50.7
5	4.4	9.6	8.0	7.0
6	0	1.7	5.3	3.0
7	43.0	29.7	35.5	27.6
8	0.4	0.2	-3.1	6.4
9	45.0	32.5	28.0	39.1
10	0	-2.0	-3.2	-6.1

by Equation (6) 0.18. The zero-intercept model (Equation 4) is clearly less effective than the other two, but there is no basis for choosing between Equations (3) and (6). Table 7 shows that all models may predict negative *Uma* densities, possibly implying a degradation of conditions beyond that necessary to eliminate the species. For all models, values of $\underline{R}^2$ are increased somewhat if negative predictions are set equal to zero.

Although Equations 3 and 6 are equally good at predicting *Uma* densities (from available data), there is an important difference between the models represented by the two equations. In the multiple regression analysis "years of stabilization" of sand ($\underline{Y}$) was not an important variable. It entered next to last and increased $\underline{R}^2$ only about 0.005. Yet the process of surface stabilization following interruption of sand flow is important in the dynamics of dunes and as an influence on the habitat of *Uma*. By incorporating this variable in a model one may, in a limited fashion, predict rates of decline in *Uma* populations in areas undergoing stabilization.

This process is illustrated in Table 8, using Equation (6) and data from Plots 2, 5, 7 and 9. The projections assume initiation of stabilization in Plot 9 and a continuation of present conditions in the other plots. Because of secondary changes in other sand variables over time, realistic projections can probably be made only over a few years retrospectively or in advance. For example, using presently observed measurements of sand in Plot 10, Equation (6) predicts that this plot would never have supported *Uma* even before the obstructing trees were planted.

Of the ten plots examined, only two (3 and 4) supported mesquite trees.

Table 8. Present and project densities ($n \cdot ha^{-1}$) of *Uma inornata* in plots in the Coachella Valley. Projections were based on Equation (6) assuming a continuation of ongoing stabilization in Plots 2, 5 and 7 and initiation of stabilization in Plot 9.

Plot	Years of stabilization	Present observed density	Present predicted density	Projected density (1982)	Projected density (1986)
2	4	16.8	12.6	8.5	3.3
5	4	4.4	7.0	4.8	1.6
7	4	43.0	27.6	21.5	13.5
9	0	45.0	39.1	27.7	15.2

These two plots had more abundant vegetation than any of the others (apparently because of more soil moisture), and exhibited greater overall relief--including areas of relatively steep slopes. Because of these differences we analyzed densities of *Uma* in the other eight plots along lines similar to those just described. In the multiple regression analysis the first four variables entered were years since stabilization, $d_{0.75}$, surface coarseness and penetrability of lee sands (Table 9). With these variables the multiple R^2 was 0.97 and the model for predicting *Uma* density was:

$$N = 100.4 - 176.8d_{0.75} + 1.3Y + 4.3P - 9.9C \tag{7}$$

By changing the coefficient of Y in Equation (5) from 0.13 to 0.05, we created another *hybrid* variable. When *Uma* densities in 8 plots were regressed on this variable the correlation coefficient was 0.97 ($R^2 = 0.94$). The predictive model was:

$$N = 8.2 \left[\frac{P}{Cd_{0.75} + 0.05Y}\right] - 20.7 \tag{8}$$

If our emphasis on "lee sand" as an important feature of total habitat is correct, then *Uma* numbers should reflect the quality of lee sands *and* their relative extent in the areas studied. Table 10 gives estimated percentages of plots composed of lee sand (A) and a habitat "quality index" computed as:

$$(A)(P)/Cd_{0.75} \tag{9}$$

Table 9. Results of multiple regression analysis involving estimated densities of *Uma inornata* in 8 plots in the Coachella Valley and six sand variables.

Variables entered	Multiple *R*	Multiple R^2	*F*-value to enter
Years of stabilization	0.690	0.476	5.45
Sand grain diameter at 75th percentile (mm), lee sand	0.852	0.726	4.57
Surface coarseness	0.941	0.886	5.59
Penetrability, lee	0.983	0.966	0.08
Percent of sand <0.1 mm in diameter, lee	0.990	0.980	1.37
Percent of sand >1.0 mm in diameter, lee	0.991	0.982	0.16

Table 10. Estimated densities of *Uma inornata* in ten areas in the Coachella Valley and habitat quality indexes based on quality and extent of sand in leeward dunes. Ranks are given in parentheses.

Plot	Estimated density of *Uma inornata* ($n \cdot ha^{-1}$)	Estimated extent of lee sand in plots (%)	Habitat quality index
1	17.2 (4)	30	1.74 (4)
2	16.8 (5)	10	0.59 (7)
3	8.8 (6)	45	2.36 (2)
4	45.5 (1)	40	11.62 (1)
5	4.4 (7)	20	0.77 (6)
6	0 (9½)	10	0.34 (8)
7	43.0 (3)	17	1.53 (5)
8	0.4 (8)	8	0.32 (9)
9	45.0 (2)	30	2.26 (3)
10	0 (9½)	1	0.02 (10)

The correlation between _Uma_ densities and the habitat quality index is statistically significant ($\underline{r} = 0.65$), but just barely so ($\underline{F} = 5.9$, $\underline{F}_{0.05} = 5.3$). A rank correlation test gives $\underline{r}_{\underline{s}} = 0.82$, significant at the 1% level. Taking this analysis at face value implies that Plots 7 and 9 sustain much higher densities of _Uma_ than would be expected from the quality and extent of lee sands.

Table 11 summarizes counts of tracks in Plots 7 and 8 during April. These findings are consistent with the more comprehensive data summarized in Table 3. In our view, counts of tracks may serve to discriminate between well populated and unpopulated areas, but it is unlikely that the technique can be precisely calibrated with absolute numbers. The principal problem is distinguishing between tracks of _Uma_ and _Callisaurus draconoides_. Distances between footprints are influenced by the speed at which lizards are moving, and all of the following species have been observed--at one time or another--to move either with the tail elevated or dragging: _Uma inornata_, _Callisaurus draconoides_, _Dipsosaurus dorsalis_ and _Crotaphytus wislizenii_. Under conditions involving finer and otherwise undisturbed sands, an experienced worker might be able to make discriminations on the basis of relative sizes of fore and hind feet as suggested by England and Nelson (1976).

Table 12 summarizes counts of _Uma_ under standardized conditions in three plots. Numbers of _Uma_ observed per man-hour are higher than those in Table 3 because counts were made under optimal conditions and no time was spent catching and/or marking lizards. For these three plots, at least, there was no useful relationship between counts and densities as estimated by capture-recapture analysis. The situation

Table 11. Counts of tracks of _Uma inornata_ in two plots in the Coachella Valley in 1980.

Plot	Date	Lizards caught	Estimated meters of cleared areas suitable for counting tracks	Number of tracks counted	Tracks per meter of cleared area
7	Apr 7	13	320	33	0.10
	9	16	320	39	0.12
	11*	7	320	0	0
	15	9	320	88	0.28
8	8	0	300	0	0
	10	0	300	6	0.02
	14	0	300	5	0.02
	16	1	300	15	0.05

* strong winds from northwest all day; blowing sand and dust; no active lizards were observed (all captured were excavated from loose sand or burrows)

Table 12. Numbers of _Uma inornata_ counted (per man-hour) in three plots in the Coachella Valley in 1980 and estimated densities of _Uma_ in these plots.

Plot	_Uma_ counted during 18 man-hours	_Uma_ observed per man-hour	Estimated density of Uma ($n \cdot ha^{-1}$)
2	79	4.4	16.8
4	75	4.2	45.5
7	33	1.8	43.0

might be improved by inspection of more plots. We can identify one particular problem associated with this technique. In Plot 7, at least half the Uma captured were dug out of burrows or loose sand. While Uma were well represented in this area they simply were not seen in proportion to estimated numbers. Terrain and degree of vegetation cover may also influence numbers of Uma observed.

England and Nelson (1976) recorded numbers of Uma tracks in areas termed "sandy plains," "mesquite dunes" and "sandy hummocks." The last type of habitat was by far the most abundant (82%) in the areas they surveyed. Relative abundances of Uma were about the same in all three types of habitats. Our data are similar in this regard. The three habitat types each included one plot with Uma densities exceeding $40 \cdot ha^{-1}$ (Plots 1, 4 and 7). Mean numbers per hectare in Plots 1, 2 and 9 (sandy hummocks) were 26.3, in Plots 3 and 4 (mesquite dunes) 27.3, and in Plots 5 and 7 (sandy plains) 23.7.

Common kinds of plants in the ten plots are listed in Table 13. Only species judged by Duncan to be "common" or "very common" are listed. Four perennials--Larrea tridentata, Croton californicus, Coldenia plicata and Dalea emoryi were common in almost every plot. Cryptantha angustifolia, Dicoria canescens and Schismus barbatus were the most widely represented annuals and grasses. Russian thistle was abundant in Plot 4, both in open areas and among mesquite trees. The presence of this species did not appear to be detrimental to Uma, but Salsola in Plot 4 did not occur in solid stands as it does in some other parts of the Coachella Valley (England, pers. comm.).

Table 13. List of common plants in 10 plots in the Coachella Valley.

Species	Plots 1	2	3	4	5	6	7	8	9	10
Shrubs										
Ambrosia dumosa			x							
Atriplex canescens		x	x	x						
A. polycarpa		x								
Coldenia plicata	x	x			x	x	x	x	x	x
Croton californicus	x	x	x	x	x	x	x	x	x	x
Dalea californica									x	x
D. emoryi	x				x	x	x	x		x
Haplopappus brickellioides			x							
Larrea tridentata	x	x	x	x	x	x	x	x	x	x
Petalonyx thurberi									x	x
Prosopis glandulosa			x	x						
Annuals and grasses										
Abronia villosa				x						
Achyronychia cooperi				x						
Astragalus crotalariae					x		x	x		
Baileya pauciradiata		x		x			x			
Camissonia claviformis		x		x			x	x		
Chaenactis fremontii							x			

Table 13 (cont.)

Species	Plots 1	2	3	4	5	6	7	8	9	10
Annuals and grasses										
Cryptantha angustifolia	x	x		x	x	x	x	x		
Dicoria canescens	x	x	x	x	x		x	x	x	x
Euphorbia polycarpa				x						
Geraea canescens		x		x						
Langloisia matthewsii	x			x						
Malacothrix glabrata							x			
Oenothera deltoides				x						
Palafoxia linearis		x	x	x			x	x		x
Phoradendron californicum				x						
Salsola kali				x						
Schismus barbatus	x	x	x	x	x	x	x	x	x	x

Discussion

The reliability of population estimates obviously has great bearing on the kind of analyses described in the foregoing section. As can be seen from Table 3, numbers of *Uma* in Plots 4 and 9 are not well defined. The low incidence of marked lizards in census data (Appendixes 4 and 7) imply that a high proportion of lizards remained unmarked in these plots. In instances where census data were amenable to analysis as a chain of samples (Plot 7 in 1980, Plot 17 in 1979) the Schumacher-Eschmeyer technique gave tighter confidence intervals than estimated for other plots. We originally intended to collect data in all plots for analysis as a chain of samples. It was also our intention to mark captured lizards with paint so that no time would be lost recapturing marked lizards (i.e., it would be sufficient to score painted lizards merely observed as "recaptured"). Because capture-recapture analyses depend importantly on the assumption that marked and unmarked individuals are equally susceptible to capture (or registration), the use of this system required that all (or almost all) unmarked lizards observed would be captured. While this was true in Plot 7, it was obviously not true in Plots 2 and 4, where a good many *Uma* were seen but not captured. This problem led us to adopt the simpler technique of marking as many different animals as possible and then carrying out a series of censuses on the final day. Our recommendation is that future censuses be carried out so as to permit use of the Schumacher-Eschmeyer method of analyzing data. Nominally, this would require that every lizard entering into the analysis be captured--not merely resighted.

A possible improvement is the system suggested by Heckel and Roughgarden (1979). These authors experimented with the use of paint on anoles in the West Indies. But lizards were marked by _spraying_, and it was never necessary to capture them. Furthermore, lizards could be given time-specific marks by using different colored paints at different times. Spraying _Uma_ with paint may not be as easily accomplished, but the idea is worth testing. The added power of more than two samples is enormous in improving capture-recapture estimates of numbers. A chain of samples also allows tests of some of the assumptions underlying these kinds of analyses.

Heckel and Roughgarden (1979) also commented that when they examined an area repeatedly they observed fewer and fewer lizards. We tested census data from plots 1-5 and 9 (Appendixes 1-5 and 7) to see if this was true of _Uma_. We computed the mean number of _Uma_ seen in the course of n censuses in a plot, then divided the number seen during each individual census by the mean. Numbers from final day censuses in five plots could then be analyzed jointly by regressing the various quotients on numbers from 1 to n. If fewer lizards were seen as repeated censuses were made, one would expect a significantly negative slope to the regression line. The correlation coefficient was -0.28, but the F-ratio (3.45, $F_{0.05}$ = 4.1) showed that the slope did not differ significantly from zero.

It is hard to judge how well the models developed in the foregoing section are rooted in biological reality. The species of _Uma_ are unusual among lizards in the extent to which their geographic distribution and local occurrence are controlled by substrates. Hence, it is reasonable to emphasize the nature of these sands in our study. However, general area attributes (like those in Table 2) did not afford any insight as to causes of variations in densities. It was not until we concentrated on characteristics of lee sand that possible interpretations of plot differences began to emerge. Nor could we simply look at individual characteristics of lee sands, only one of which was significantly correlated with Uma density. However, combinations of several factors relating to lee sand quality (and/or the history of the study areas) explained substantial amounts of variation observed in abundances of Uma.

Historical precedents certainly justify a focus on sand in leeward situations (Stebbins 1944, Norris 1958) but some of Pough's (1970) observations are at odds with these earlier ideas. Pough observed that Uma retreated at night to the windward ends of small dunes. He also stated that, "In laboratory choice experiments lizards preferred sand from the windward ends of these dunes to coarser or finer sand." This remark suggests that sand grain size is really what is important, and this is in keeping with the earlier assertions of Stebbins and Norris. The contradiction lies in where the most favorable sand is expected to occur. Stebbins (1944) wrote: "Most of the sand in the dune area and on the lee side of...hummocks is extremely fine, measuring, on the average, under 0.5 mm." And Norris (1958) stated: "The windward slope [of sand hummocks] is composed of coarse sand...while the leeward side ...possesses a long stringer of fine sand." Weaver's measurements of grain diameters in windward and leeward positions do not clarify the situation. The overall mean diameter of windward grains (based on means from 10 plots) was 0.278 mm; the overall mean diameter of leeward grains from the same plots was 0.273 mm (Weaver 1980). The mean diameter of leeward grains in Plot 8 was about twice the diameter of windward grains; in Plot 10 the windward grains were 1.85 times the size of the leeward grains. In the three most densely populated plots (4, 7 and 9) ratios of mean diameters of leeward grains to mean diameters of windward grains were 0.78, 1.11 and 0.71, respectively. Do we need to evaluate the use of specific microhabitats by Uma more precisely in order to assess the actual worth of a more general habitat?

The 3-term multiple regression model (Equation 3) and the model based on a single hybrid variable (Equation 6) both explained about 81% of the observed variation in the dependent variable. The second model is a little more flexible in that it gives more scope for intuition and permits us to force variables to act in an incremental or decremental way. Both models incorporate one variable ($\underline{d}_{0.75}$) which has no obvious ecological significance relative to other sand size gradation parameters, as well as non-zero intercepts. In Equations (6) and (8) the negative intercepts may be partly associated with the fact that, although densities of zero were observed, the first terms of the equations could only assume values greater than zero. The predictive capabilities of all of these models can be gauged only in terms of the actual sites evaluated. Investigations of other areas, where attributes of sand might range beyond those values encountered in Plots 1-10, would lead to models with different coefficients for variables--although not necessarily of differing structure.

In spite of these problems, it is clear that the density of Uma varies conspicuously in different habitats in the Coachella Valley.

Although we do not understand all the bases for this variation, data from the six experimental plots (5-10) show that obstructions to wind flow and ensuing sand depletion and surface stabilization affect the occurrence of *Uma inornata*. The three plots downwind of obstructions (6, 8, 10) have been subjected to these processes for 7, 12 and 17 years, respectively, and in all three situations changes in qualities of aeolian sand, and possibly in related biological variables, have rendered the areas unsuitable as *Uma* habitat. The continuing reception of new sand appears, then, to be an indispensable ecological process insofar as the survival of fringe-toed lizards is concerned. The importance of rates of sand passage is less clear. The three plots exhibiting highest densities of *Uma* (4, 7 and 9) sustain, respectively, passages of 1, 6 and 20 yd^3 per foot-wide path. These observations suggest that some active passage of sand is necessary, with the rate of sand transport less important.

How far beyond an obstruction may one expect to observe effects of the interruption of natural sand movements? The downwind progression of sand depletion and surface stabilization with time and distance have been discussed by Weaver (1979), and further examined in terms of our study of *Uma inornata* (Weaver 1980). Briefly, Weaver contends that any substantial obstruction, i.e., one blocking a path a few hundred meters in width, or more, and capable of continued impoundment of sand, will eventually result in sand depletion and surface stabilization over an area extending downwind the length of the region. Weaver (1980) has illustrated areas so affected and others which appear threatened. Exactly how abundances of *Uma* occupying such downwind strips may change over time is not presently predictable. However, the foregoing discussion implies that the ultimate disappearance of the species in such areas is only a matter of time. If this be true, the total area presently occupied by _Uma_ is deceptive, because some of these habitats are already undergoing changes which will render them uninhabitable.

Finally, all of the foregoing discussion must be tempered by the fact that various biological factors--as well as sand variables--influence the occurrence and abundance of _Uma_. We have already commented on the presence of mesquite trees in Plots 3 and 4, and how the presence of these trees may complicate our understanding of _Uma_ numbers. England and Nelson (1976) concluded that apparent numbers of _Uma inornata_ were positively correlated with the vigor of vegetation, possibly because of increased numbers of insects on which _Uma_ subsists. Future studies of the present status and future of _Uma inornata_ in the Coachella Valley will have to take all of these factors into account.

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APPENDIX 1

Sampling data for *Uma inornata* in Plot 1, June 1980

Number females registered: 14

Number males registered: 16

Total *Uma* marked (*a*): 30

Census data for final day

Census	*n*	*r*	Population estimate ($\hat{N}$) $a(n+1)/(r+1)$	Estimated variance of ($\hat{N}$) $a^2(n+1)(n-r)/(r+1)^2(r+2)$
1	8	7	33.75	14.06
2	3	3	30.00	0
3	7	5	40.00	57.14
4	7	4	48.00	144.00
5	8	5	45.00	96.43
6	6	5	35.00	25.00
7	3	2	40.00	100.00
means			38.82	62.38
standard deviations (*s*)			6.377	7.898
1.96*s*			12.5	15.5

APPENDIX 2

Sampling data for Uma inornata in Plot 2, April-May 1980

Number females registered: 9

Number males registered: 16

Total Uma marked (a): 25

Census data for final day

Census	n	r	Population estimate ($\hat{N}$) $a(n+1)/(r+1)$	Estimated variance of ($\hat{N}$) $a^2(n+1)(n-r)/(r+1)^2(r+2)$
1	8	6	32.13	28.70
2	8	6	32.12	28.70
3	9	6	35.73	47.83
4	4	3	31.25	39.06
5	5	3	37.50	93.75
6	5	3	37.50	93.75
7	11	4	60.00	350.00
8	9	6	35.73	47.83
means			35.75	91.20
standard deviations (s)			9.331	9.550
1.96s			18.3	18.7

APPENDIX 3

Sampling data for *Uma inornata* in Plot 3, May 1980

Number females registered: 7

Number of males registered: 3

Total *Uma* marked (*a*): 10

Census data for final day

Census	*n*	*r*	Population estimate ($\hat{N}$) $a(n+1)/(r+1)$	Estimated variance of ($\hat{N}$) $a^2(n+1)(n-r)/(r+1)^2(r+2)$
1	5	2	20	50.00
2	3	1	20	66.67
3	6	4	14	9.33
4	2	0	30	300.00
5	3	1	20	66.67
6	2	1	15	25.00
7	1	0	20	100.00
means			19.86	88.24
standard deviations (*s*)			5.186	9.394
1.96*s*			10.2	18.4

APPENDIX 4

Sampling data for *Uma inornata* in Plot 4, April-May 1980

Number females registered: 17

Number males registered: 26

Total *Uma* marked (*a*): 43

Census data for final day

Census	*n*	*r*	Population estimate ($\hat{N}$) $a(n+1)/(r+1)$	Estimated variance of ($\hat{N}$) $a^2(n+1)(n-r)/(r+1)^2(r+2)$
1	15	6	98.30	679.22
2	10	2	157.67	4519.78
3	7	3	86.00	739.60
4	6	1	150.50	5392.92
5	8	5	64.50	198.11
6	3	2	57.33	205.44
means			102.4	1955.85
standard deviations (*s*)			42.712	44.223
1.96*s*			83.7	86.7

APPENDIX 5

Sampling data for *Uma inornata* in Plot 5, May-June, 1980

Number females registered: 7

Number males registered: 3

Total *Uma* marked (*a*): 10

Census data for final day

Census	*n*	*r*
1	1	1
2	1	1
3	2	2
4	5	5
5	4	4
6	2	2
7	2	2
8	2	2

APPENDIX 6

Sampling data for Uma inornata in Plot 7, April 1980

Number females registered: 21

Number males registered: 17

Total Uma marked: 38

Census data, April 7-15

Dates	X_t [1]	n_t [2]	x_t [3]	$x_t X_t$	$n_t X_t^2$
April 9	13	16	2	26	2704
April 11	27	7	2	54	5103
April 15	32	9	3	96	9216
Totals				176	17023

[1] number of marked animals at risk at time of census

[2] number of individuals in census

[3] number of marked individuals in census

$$\hat{N} = \Sigma n_t X_t^2 / \Sigma x_t X_t$$

APPENDIX 7

Sampling data for Uma inornata in Plot 9, May-June, 1980

Number females registered: 14

Number males registered: 21

Total Uma marked (a): 35

Census data for final day

Census	n	r	Population estimate ($\hat{N}$) $a(n+1)/(r+1)$	Estimated variance of ($\hat{N}$) $a^2(n+1)(n-r)/(r+1)^2(r+2)$
1	8	2	105.00	1837.5
2	2	0	105.00	3675.0
3	4	0	175.00	12,250.0
4	4	1	87.5	1531.25
5	6	1	122.5	3572.92
6	4	3	43.75	76.56
7	1	0	70.00	1225.0
means			101.25	3452.60
standard deviations (s)			41.625	58.764
1.96s			81.6	115.2

APPENDIX 8

Simple linear regressions of *Uma* densities on 38 independent variables based on observations in ten plots in the Coachella Valley.

$F_{0.05} = 5.3$, $F_{0.01} = 11.3$.

Variable	*r*	*F*-ratio
Mean present annual rate at which aeolian sand is received (yd^3 ft-wide path)	0.52	2.91
Years of stabilization (number of years since receipt of new sand)	-0.55	3.49
Penetrability (1 ft drop test)		
windward	-0.60	4.41
leeward	0.43	1.83
typical sand, in open	-0.01	0.00
coarse sand, in open	0.00	0.00
weighted mean (all situations)	0.06	0.03
Crustiness index		
windward	0.67	6.61*
leeward	-0.25	0.55
typical sand, in open	-0.05	0.02
coarse sand, in open	0.07	0.04
weighted mean (all situations)	0.11	0.09
Surface stabilization index	-0.44	1.90
Mean grain size (mm)		
windward	-0.34	1.05
leeward	-0.46	2.14
typical sand, in open	0.05	0.02
coarse sand, in open	-0.30	0.81
weighted mean (all situations)	-0.34	1.04

APPENDIX 8 (concl.)

Variable	r	F-ratio
Median grain size (mm)		
windward	-0.28	0.67
leeward	-0.35	1.13
typical sand, in open	0.02	0.00
coarse sand, in open	0.36	1.17
weighted mean (all situations)	-0.28	0.70
Sorting coefficient		
windward	-0.45	2.03
leeward	-0.53	3.10
typical sand, in open	-0.26	0.56
coarse sand, in open	-0.34	1.03
weighted mean, (all situations)	-0.57	3.88
% (by weight) finer than 0.1 mm		
windward	-0.15	0.18
leeward	-0.17	0.24
typical sand, in open	-0.39	1.42
coarse sand, in open	-0.13	0.13
weighted mean, (all situations)	-0.37	1.24
% (by weight) coarser than 1.0 mm		
windward	-0.42	1.77
leeward	-0.66	6.21*
typical sand, in open	-0.26	0.57
coarse sand, in open	-0.24	0.51
weighted mean, (all situations)	-0.41	1.63

PART II

Aeolian Sand Transport and Deposit Characteristics at Ten Sites in Coachella Valley, California

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Photography by

Jan G. Windhausen

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Abstract

Characteristics of aeolian sand transport and deposits at ten sites in the Coachella Valley were examined during mid-1980. Aeolian sands in the valley represent the sole habitat of the Coachella Valley Fringe-toed Lizard, _Uma inornata_, a potentially endangered species due to extensive development and other human actions. _Uma_ abundance at the ten sites was determined concurrently by a team of biologists.

Six of the plots were in pairs, with one member of each pair located in a natural aeolian sand transport and deposit environment. The other, nearby member was shielded from the natural receipt of wind transported sands by a tamarisk tree row barrier, yet positioned sufficiently far from the trees to remain subject to natural wind velocities and, hence, to sand depletion and surface stabilization processes. The remaining four plots were in mesquite dune or sandy hummock areas.

Characteristics evaluated include natural and present rates of sand transport, number of years since receipt of new sand, penetrability, crustiness, size gradation and sorting coefficient of near-surface deposits, and coarseness of the surface layer of grains, all suspected of possibly influencing _Uma_ behavior and abundance. Evaluations were made for

four microenvironments or microhabitats within each of the ten plots.

Dynamics of the basic aeolian sand transport system operating in the valley had previously been studied and quantified. Secondary, surficial deposit forms, superimposed upon the basic sand transport system environment, are classified here and changes which the various characteristics studied undergo in response to natural fluctuations in aeolian sand transport system dynamics and to human actions are discussed. Description of current and anticipated near-future conditions is also presented.

Data resulting from this study were analyzed in conjunction with the results of the companion biological study and reported in <u>The Abundance of the Fringe-toed Lizard (*Uma inornata*) at 10 Sites in the Coachella Valley, California</u>, by Turner, Weaver and Rorabaugh. Despite visually obvious overall differences between most of the plots in the field, differences in individual textural characteristics were quite subtle. In the companion study no significant correlations were found between individual characteristics and the observed *Uma* densities, although analyses involving combinations of characteristics elicited several highly significant relationships. Appropriate mathematical models for predicting *Uma* densities based upon certain combinations of aeolian sand transport and deposit characteristics are presented in the companion study report.

Effects of shielding upon the characteristics studied and upon _Uma_ abundance are discussed and evaluated herein. In time these effects extend to the downwind end of the valley and render the shielded area unsuitable as _Uma_ habitat. Further research suggestions are offered.

Introduction

The transport of sand by wind occurs as a natural geologic process in Coachella Valley, Riverside County, California. The environment associated with this aeolian sand transport system, and particularly the deposits themselves, represent the sole habitat of the Coachella Valley Fringe-toed lizard, *Uma inornata* (Stebbins 1944, Norris 1958). Mosauer (1935), Mayhew (1965) and Pough (1970) further cite general relationships between the animal and various characteristics of its aeolian sand habitat.

England and Nelson (1976) indicate the historical range of the species to have been about 324 mi^2, which probably included some 200 mi^2 of suitable habitat. Aerial photographs taken in 1979, and ground survey conducted in 1975, indicate continuing agricultural and urban development of the valley to have directly resulted in the reduction of suitable habitat to some 99 mi^2 (Federal Register, 1980). As a result, in mid-1980 the species was being considered for listing as endangered by the State of California, and for declaration as threatened, with critical habitat determination, by the Department of Interior.

More insidious than the direct loss of habitat area to development, and of most recent concern, is the indirect effect of land development and other human actions on otherwise undisturbed habitat areas downwind. Weaver (1979) indicates that areas shielded from the natural continuing receipt of windblown sand undergo changes in the form of sand depletion and surface stabilization and that, in time, these effects will extend to the downwind end of the region. Awareness of the general relationships between _Uma_ and sand deposit characteristics has led biologists and others to believe that changes which occur in shielded areas are probably detrimental to the animal's habitat. Effects of existing land developments and other barriers to the natural sand transport process, together with anticipated continuing development activity and other project proposals, such as flood control measures which would result in 50% to 100% reductions in windblown sands entering the valley from the west (U.S. Army Corps of Engineers, 1979), emphasize the need for further definition of the relationship between _Uma_ and its aeolian sand habitat and of the changes in habitat characteristics which occur in shielded areas.

Brief, companion studies of aeolian sand transport and deposit characteristics and of _Uma_ abundance were planned during the early spring of 1980. Six sites (3 pairs) were selected, with one member of each pair shielded by an obstruction to the natural sand transport process. Pair members were located sufficiently close together to have been subjected to essentially the same sand transport conditions and to have exhibited the same deposit characteristics and presumably the same Uma densities prior to the barrier's presence. Additionally studied were 4 sites representative of what England and Nelson (1976) classified as sandy hummock and mesquite dune types of habitat. The general locations of the ten study sites are shown on Exhibit 1, Area Map.

Purpose of the study described herein was to select and quantify aeolian sand transport and deposit characteristics affording reasonable possibilities of influencing Uma behavior and population density within each of the 10 study sites. Deposit characteristics were evaluated for 4 microenvironments: windward and lee hummock deposits, and typical intervening and coarsest intervening sandy deposits. Proportionate areas represented by each of the microenvironments were estimated visually. Three general types of deposit characteristics were examined: sand size gradation, surface penetrability and surface coarseness. Also evaluated were basic aeolian sand transport data, such as natural and present rates at which sand is received at the various sites and the number of years which several of the sites have been deprived of the receipt of new sand.

Data yielded by this study supplemented the parent biological study (Turner et al, 1980) which includes determination of Uma densities for the 10 study sites and correlation analyses of those observed

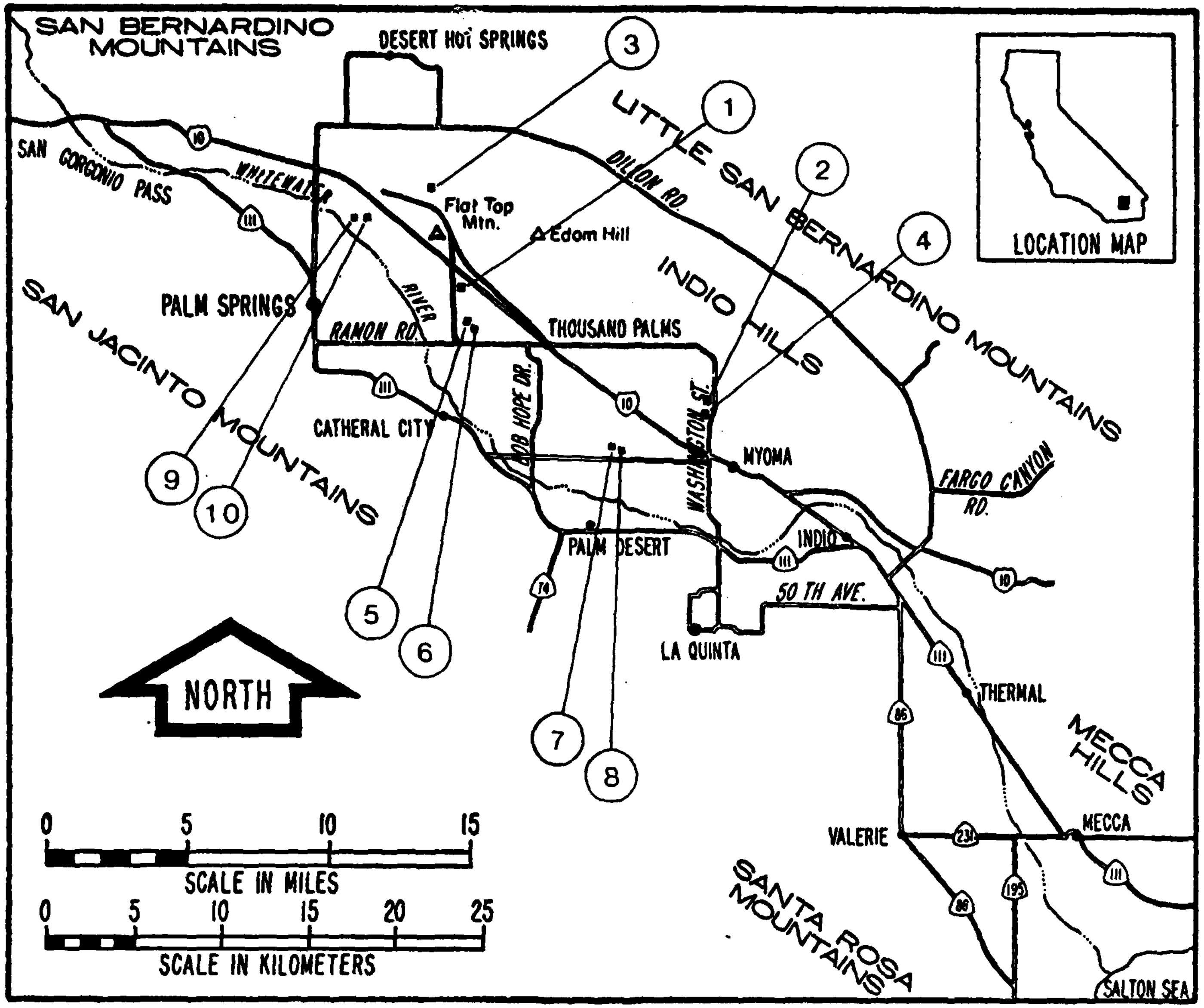


Exhibit 1. Area Map of Coachella Valley, California, showing locations of study sites.

densities with the habitat variables provided herein. We anticipated that the combined studies would clarify the effects of shielding on _Uma_ abundance. It was less certain whether the relationships between _Uma_ abundance and aeolian sand variables would permit reliable predictions of densities at other locations based upon aeolian sand characteristics.

Following review and analysis of the combined data, and realization of the dramatic effects of shielding upon _Uma_ abundance, it was decided to incorporate additional information and discussion on shielding into this report as an aid to future studies.

Background

General relationships between *Uma inornata* and its aeolian sand environment are thoroughly discussed in Turner et al (1980). Weaver (1979) describes the geographics and dynamics of the basic regional aeolian sand transport system, a summary of which is appropriate here as background for subsequent discussion of surficial deposit forms.

The region of major aeolian sand transport activity covers an area of approximately 340 km^2, extending some 55 km from near Cabazon in the eastern San Gorgonio Pass to southerly of Indio. The region lies primarily between the San Jacinto Mountains and the Whitewater River channel on the southwest and the San Bernardino Mountains and the Indio Hills on the northeast, exhibiting a maximum width of about 18 km. It is situated entirely within the Whitewater River basin.

Sands supplied by floodwaters to the westerly and northerly portions of the region are transported to the southeast by a strong, unidirectional wind regime. Transporting winds emanate from the San Gorgonio Pass and occur most frequently and with greatest intensity during spring and early summer. Upon entering the valley, the winds tend to dissipate rapidly in the southeasterly direction, losing their capability of transporting significant quantities of sand before reaching the Indio area.

The basic transport system can be conceived as a continuous sheet or stream of sand, intermittently flowing from northwest to southeast, resulting in a continuing, gradual decrease, or removal of sand from the occasionally replenished source areas and an increase, or accumulation in the downwind deposition area.

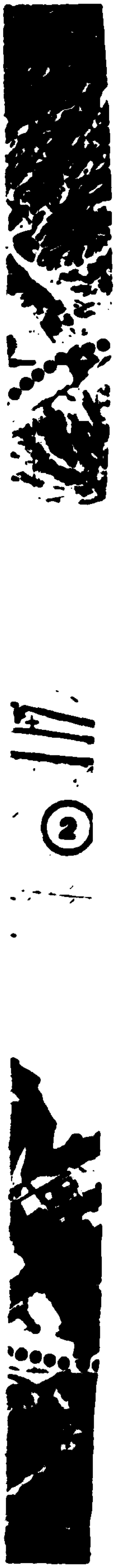
The alluvial plain of the Whitewater River extending between Windy Point and Indian Avenue, and the coalescing alluvial fans along the base of the Indio Hills constitute the primary source areas. The large accumulation or basic deposition area extends over the southerly and easterly portions of the region. Between the source areas and the basic deposition area lies an intermediate transport area across which sands tend to be expeditiously transported. This area exists as a result of the wind regime being capable of transporting more sand than is normally available to it over the long term. Thus, the basic tendency is for the area to be swept free of sand.

The upwind edge of the basic deposition area represents the location where the transport capability of the diminishing wind regime has been reduced to just equal the long term availability of sand. Beyond, extending to the southeast, continuing reduction in transport capability results in continuing deposition.

Note that water-laid alluvium constitutes the basic substrate in the source and intermediate transport areas, whereas the natural surface of the deposition area is comprised solely of wind deposited sand.

The pattern of sand movement is extremely stable, with transport being essentially unidirectional at any given location within the region. This results in a longitudinal division of the region into the Whitewater subregion, which receives its supply of sand from the Whitewater River and its upper basin tributaries, and the Indio Hills subregion, supplied by and through the Indio Hills. The regional boundary, the basic deposition area, sand movement pattern and the subregional dividing line are all indicated on Exhibit 2.

System dynamics, considered in terms of transport rates, source depletion rates, frequency of occurrence of transport conditions and size gradation of sands being transported, are most significantly influenced by fluctuations in the hydrologic provision of sand and in the transporting wind regime, and to a lesser extent by fluctuations in vegetative cover. Changes occurring in the basic system, in turn, effect changes in surface and near-surface textural characteristics of all aeolian deposits throughout the region. In simplest terms, greater availability of sand for transport tends to result in the surface sands in the basic deposition area becoming finer, stronger winds cause them to become coarser, and greater than normal



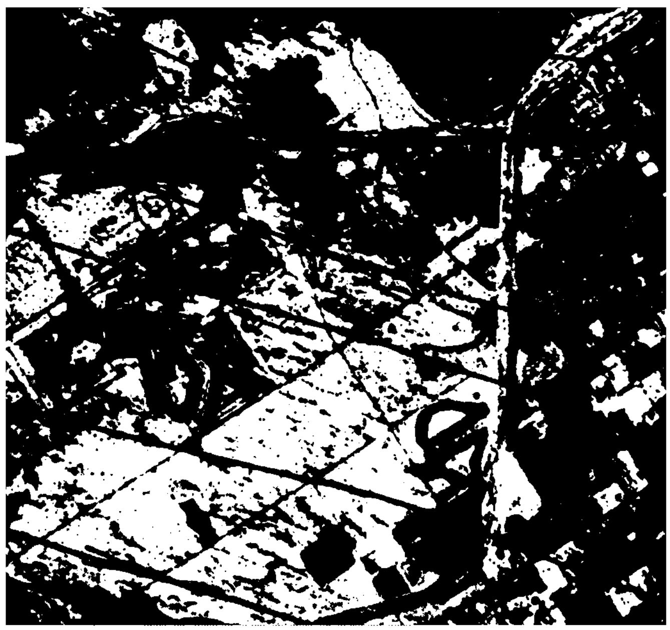
2

1


3
PALM DRIVE
VARNER ROAD
Flat Top Mountain
Garnet Hill
ROUTE 10
SPT Co
INDIAN AVENUE
VISTA CHINO
Palm Springs
RAMON ROAD
ROUTE

VARNER ROAD
1000 Palms
ROUTE
S P T Co
INDIO HILL
WHITEWATE
1
5
6
DATE PALM DRIVE
BOB HOPE DRIVE
Rancho Mirage
COUNTRY CLUB DRIVE
Cathedral City


PALM CANYON ROAD
WASHINGTON
1000 Palms
ROUTE
INDIO HILLS SUBREGION
WHITEWATER SUBREGION
7
8
2
BOB HOPE DRIVE
Rancho Mirage
COUNTRY CLUB DRIVE
Indian Wells
Palm Desert



REFERENCE MAP

LEGEND

5 STUDY SITES

SAND MOVEMENT DIRECTION

DEPOSITION AREA BOUNDARY

AEOLIAN SAND TRANSPORT
REGIONAL BOUNDARY

AREAS PRESENTLY DEVELOPED, STABILIZED OR DESTINED FOR STABILIZATION

0 1 2 3

SCALE IN MILES

.EY UDY	FLIGHT DATE: NOV. 26, 1974 SEPTEMBER 1980	EXHIBIT 2

vegetation tends to subdue transport activity as a whole.

Superimposed upon the basic sand transport system environment described to this point, and of major importance to *Uma* habitat considerations, is a secondary system of surficial deposit forms. These can be classified as follows, after Beheiry (1967), who extensively describes their morphology:

a) hummocks (Beheiry's knob dunes)

b) mesquite dunes

c) sand drifts

e) sand veneers

f) sand undulations

g) wave and barchan-like dunes

All are dependent upon and are affected by changes in the basic transport system.

Hummocks, by far the most prevalent of the forms, are those deposits which accumulate in the wind shaded areas associated with individual vegetative shrubs. Normally a smaller upwind or windward deposit accompanies the major downwind, or lee deposit, with the combination generally being referred to as a single hummock. Size and shape are largely dependent upon the aeolian sand transport environment and the physical characteristics of the shrub. Hummocks commonly range in height from about 0.5 m to 2 m and tend to extend upwind from 1 m to 4 m and downwind from 2 m to more than 15 m.

Lee deposits, being formed largely by airborne grains moving into relatively dead air space and falling into place (rather than being propelled) generally are comprised of finer-textured sands, are less compacted and offer less resistance to penetration than their upwind counterparts. These lee deposits are generally favored by Uma for its submergence actions (Stebbins 1944, Norris 1958).

In response to changes in the basic sand transport system, hummocks tend to increase to maximum size when winds are laden to their capacity to transport sand and to diminish when winds are unladen. Thus, prolonged lack of sand available for transport can result in near total elimination of the deposits. Hummock depletion is generally evidenced by uncovered root structure of the involved shrub appearing above any remaining deposits. Total depletion leaves only slight mounds of coarse residual grains where the hummock once existed. The extent of ultimate depletion is further governed somewhat by the physical characteristics of the shrub and by location within the region.

Creosote, Larrea tridentata, is the primary shrub associated with hummock deposits, although saltbush, burrobush, cheesebush and other species also induce deposits of the same form. These types of vegetation occur throughout the valley, but trend from being more scarce in the west and north, where individual shrubs are occasionally spaced more than 15 m apart (and in some areas are virtually non-existent), to being more profuse in the eastern and southern portions. Even under these conditions, shrub characteristics and spacing can result in extensive coalescing of the induced hummock deposits as far west as Palm Drive.

Substrates between hummocks range from water laid gravels and coarser alluvium, to fine wind blown sands, to caked silt and clay size particles. As noted by England and Nelson (1976), all combinations of hummock size and intervening substrate can be found in the valley. Hummocks in various states of luxuriance and depletion, together with a variety of intervening substrate conditions appear in several of the photographs referred to in the following section. Sandy hummock environments comprised 82% of the suitable Uma habitat identified by England and Nelson (1976). These included various combinations of hummocks and intervening surface conditions, some involving other surficial deposit forms.

Mesquite dunes exist primarily in an area northwest of Edom Hill, and more extensively, scattered throughout the easterly portion of the Indio Hills subregion. Lesser occurrences are to the north, in the Desert Hot Springs area, and to the southeast, toward the Salton Sea. Mesquite thickets, usually enhanced by the presence of other lesser shrubs, impound and anchor wind blown sand in large, distinct formations. Individual dunes characteristically evolve as circular mounds, some of which approach 15 m in height and exceed 100 m in diameter. Less common, though covering more extensive areas, are large amorphous, billowy appearing masses, which can exhibit considerable internal vertical relief. England and Nelson (1976) noted 5 locations where these larger dune systems exist.

Mesquite shrubs, Prosopis glandulosa, are commonly known as water indicator Redo Plants associated with an abundance of available ground water, often at depths of several tens of meters. However, their presence in the aeolian sand transport environment appears also to be influenced by the rate at which sand is received. Physical characteristics of the shrub render it a highly efficient trap for intercepted sand. Consequently, to escape self-induced burial, the plant must be able to outgrow the rate at which the impounded accumulation increases in size. Within the region, mesquite dunes are found only in areas receiving a mean of less than about 2 cubic yards per foot-wide path of sand movement per year, as mapped by Weaver (1979). As the dune increases in size, the capability of the sand mass itself to absorb and make available additional moisture for plant growth is enhanced. These dunes often reside in an otherwise sandy hummock environment. However, distinct individual hummocks seldom are found within the confines of the mesquite dune formations.

The mesquite dunes situated northwest of Edom Hill owe their existence to the combined presence of a high water table occurring along the Banning fault of the San Andreas fault system and minor localized transport of sand from the Mission and Morongo Creek washes to the west. These dunes are esentially unrelated to those farther to the east.

Under natural conditions mesquite dunes appear to have extensively covered the eastern portion of the Indio Hills subregion. The writings of Cowles (1977) recounting his studies during the 1930's, and comments offered by Dr. Wilbur W. Mayhew of the University of California, Riverside, and by Sid England (both pers. comm.), suggest this may have constituted the prime Uma habitat prior to the 1940's. Since then, virtually all of the area southerly of the Whitewater River channel, and much to the north, has succumbed to agricultural and urban development, obliterating all but minor, scattered evidence of the natural condition.

In an active aeolian sand transport environment, mesquite dunes tend to continue to increase in size. Beheiry (1967) discusses waning characteristics, including death of the bushes and loss of considerable mass, but concludes that whether rebuilding occurs or the dune vanishes completely is difficult to verify in the field. Changes in deposit characteristics induced by changes in the sand transport process are considerably restrained in comparison with the other surficial deposit forms. This is due to the lower energy wind environment and the more uniform, finer deposits associated with the mesquite dunes. Certainly windward deposits reflect the characteristics of any recently received sands and become coarser during periods when little or no sand is available to winds capable of transport. Surface deposits within the formations themselves are normally well-protected by vegetative cover and probably undergo little change over even extended periods of time. When deprived of new sands indefinitely, the fate of these forms and the effects upon Uma habitat quality are unclear. However, if freshness of deposits is important to Uma, interminable lack of new sand must eventually be detrimental. When surveyed in 1975 by England and Nelson (1976), mesquite dunes comprised only 6% of the total habitat identified, no doubt considerably reduced from the natural condition.

Sand drifts are deposits which occur in the wind shadows of non-vegetative physical features and surface irregularities, and on insurmountable windward slopes. These deposits are associated largely with the more major physiographic features located in the westerly and northerly portions of the region, such as Windy Point, Garnet Hill, Flat Top Mountain and Edom Hill. Depressions, gullies, and the lee side of cliffs and rock outcrops occurring in the surfaces of these features all tend to harbor drift deposits. In some locations in the intermediate transport area, large boulders and rock clusters are effectively responsible for drifts exhibiting hummock-like characteristics. Due to the impervious and relatively permanent nature of the physical features involved, the basic mass of these types of deposits is generally quite stable. However, the deposit surfaces themselves tend to be quite active, evidenced by their typically smooth, bare condition. Here also, surface deposits reflect the gradation of any recently received sands, whereas unladen winds cause their gradual coarsening as the finer, more susceptible grains are removed.

Extensive drift deposits exist in the lee of Flat Top Mountain and against the westerly and northwesterly flank of Edom Hill. Beheiry (1967) discusses these in detail, noting that a combination of rainfall, runoff, gravity and subsequent winds limits the size which they can achieve.

Where accompanied by hummocks, drift deposits serve as intervening sandy substrate. This combination is most extensive in the pass area between Flat Top Mountain and Edom Hill, noted by several biologists as being highly suitable habitat (Norris 1958, Mayhew 1965).

Sand veneers are relatively thin, smooth surfaced, surficial deposits which occur extensively within the source and intermediate transport areas. Aside from sand drifts, as described, veneers represent what sandy substrate is to be found in these areas. Invariably, these aeolian deposits are protected by a layer of coarse sand and pebbles, or a vegatative cover. Essentially, they are the product of sand being transported over small scale surface features and irregularities, and areas where relatively low-lying vegetation acts to impound and shield minor deposits of limited thickness. Rarely do these veneers exceed more than a few centimeters in depth, nor do they rise above the highest projections of the underlying alluvium or other non-aeolian substratum over any appreciable area. Veneers occurring in and near the source areas generally grade into alluvial surfaces, whereas those in the intermediate transport area grade into the large accumulation representing the basic deposition area. Similarly, those in the source area tend to be more transitory and subject to more radical and rapid changes than those nearer the basic deposition area.

Where and when veneers exist, they also grade into other surficial deposit forms which happen to be distributed among them. And, as with other surficial deposit forms in these areas, the near-surface textural characteristics of veneers are responsive to

AD-A137 364 THE EFFECT OF BLOWSAND REDUCTION ON THE ABUNDANCE OF THE FRINGE-TOED LIZA..(U) CALIFORNIA UNIV LOS ANGELES LAB OF NUCLEAR MEDICINE AND RADIA.. F B TURNER ET AL. 2/2

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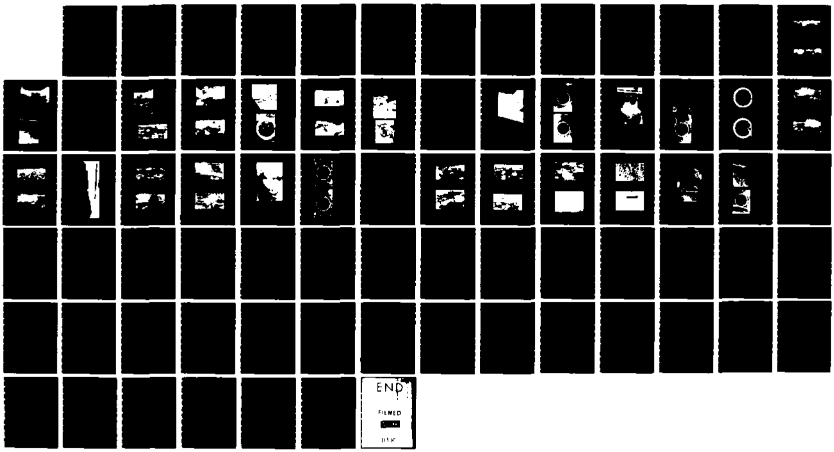

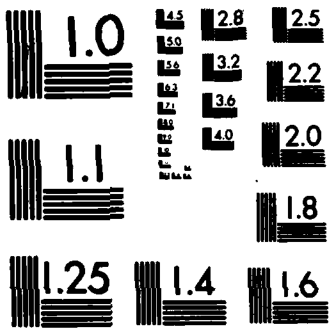

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

changes in the relationship between wind transport capacity and actual sand transport.

Technically, veneers also occur within the basic deposition area, induced by low vegetative cover. There, however, it is simpler merely to consider all relatively smooth sandy substrate as the cumulative product of the basic aeolian sand transport system rather than as a superimposed surficial deposit form.

Surficial deposits which occur within the aeolian sand transport environment independently of fixed surface features range from small surface undulations of vertical relief of a few tenths of a meter and areal extent of a few m^2, up to wave and barchan-like dunes, some with active slip faces approaching 10 m in height. Undulations occur in the surface of the large sand accumulation and undergo essentially the same surface and near-surface textural responses to changes in the sand transport environment as described previously for that sandy substrate. Undulations are most common in the central portion of the basic deposition area, within the Whitewater subregion. England and Nelson (1976) included approximately the northwesterly two-thirds of these surface features within their sandy plains habitat classification. Overall, their sandy plains area extended southeast from the vicinity of Edom Hill and Flat Top Mountain to east of Bob Hope Drive, and comprised 12% of their identified suitable *Uma* habitat. Yet further to the southeast, where vegetation becomes more plentiful, the sand undulations grade into either a series of vague sand mounds anchored by relatively dense vegetation or a small field of wave and barchan-like dunes. Both situations effectively mark the downwind termination of sand transport. Prior to partial destruction by urban development, the small dune field effectively graded into near-inactivity within itself and was truncated at its downwind end by the Whitewater River wash.

Two, likewise small wave and barchan-like dune formations presently exist in the Indio Hill subregion; both roughly 1 to 2 km west of Washington Street, one about 2 km north and the other 1 km south of Interstate Highway 10. In total, the three areas comprise less than 2 km^2. Thus, although apparently constituting acceptable Uma habitat (Mosauer 1935, Cowles 1977) these most visually remarkable aeolian sand forms within the valley are of limited significance in terms of overall habitat. England and Nelson (1976) chose to include them within their sand hummocks and mesquite dunes classifications.

Sand hummocks, drifts, and veneers also occur quite extensively in a few isolated areas near Windy Point and extending westerly along State Highway 111 and the San Gorgonio River channel to the vicinity of Fingal Point. This latter location represents both the upwind limit, or beginning of the aeolian sand transport region as well as the westerly extent of Uma habitat (Norris 1958). Since Uma ventures at most about 50 yd from the nearest windblown deposits (Norris 1958), fluctuations in the existence of such deposits on the floodplain extending between Windy Point and Indian Avenue occasionally isolate populations in these generally more consistent habitat areas near Windy Point and to the west from the main contiguous habitat. England and Nelson (1976) also found Uma present in several areas of localized deposits north and east of the primary aeolian sand transport region, representing minihabitats which may no longer or rarely afford transmigratory contact with the main habitat.

Sands involved in the aeolian transport system have been thoroughly examined and commented upon by Reed (1930), Sharp (1964) and Proctor (1968), among others. Essentially, sands supplied to both subregions are derived from similar parental rock formations. Feldspar is the most abundant constituent, with orthoclase more common than plagioclase. Quartz is next in abundance. Rarer minerals include green hornblende, muscovite, biotite, epidote, apatite, titanite, zircon and garnet. Biotite, due to the unusual aerodynamic property of its flakes, exists in greater abundance in finer deposits. Where found, finer deposits thus tend to be somewhat darker than the slightly grayish white appearance of the more common, coarser sands present throughout most of the region. Viewed at a distance of a few meters, the more prevalent coarser deposits are slightly peppered in appearance. Closer, a slight pinkish tint emerges. Finally, inspection of the individual grains reveals a myriad of colors among the rarer minerals. Individual grains range from subangular to angular, with smaller grains tending to be slightly more angular than the larger ones. Only the softer biotite flakes exhibit notable wear due to aeolian transport. Thus, in summary, except for the sorting anomaly associated with the biotite flakes, aeolian sands deposited throughout the region are believed to exhibit no significant mineralogical differences.

How does the condition of the valley at present compare with the long-term average, and what might be expected in the near future? Of greatest significance is the fact that much of the region is presently developed or artificially shielded from the natural receipt of wind blown sand, the effects of which are discussed later. Next in importance is the overabundance of vegetation which prevails throughout the valley. This condition, resulting from abnormally high rainfall over several successive years, has effectively quelled the movement of sand within all but the upper portions of the region for the past 4 years. Extensive quantities of sand presently exist in both source areas. In the case of the Whitewater subregion, continuing disturbance of surface conditions on the floodplain between Windy Point and Indian Avenue by Coachella Valley Water District percolation basin construction operations has further added to the availability and susceptibility of sands for transport. Transport across Indian Avenue as observed by the author, has been quite high in 1979 and 1980. Yet, aside from the sand which has been intercepted and stabilized by the Riverside County Road Department, Massey Sand and Rock Co., and the Southern Pacific Transportation Company, Redo the large volumes transported have been effectively absorbed by the overabundant vegetation, aided slightly by the limited trapping capacity of non-vegetative features within the intermediate transport area. The sand transport-inhibiting qualities of vegetative cover are well demonstrated in the area extending approximately 1.5 km immediately south of the railroad. Nonetheless, the sand transport process will prevail, in time, perhaps aided by a period of lesser rainfall and recession of the vegetative cover.

Major supplies of sand to the Indio Hills subregion tend to be more extensive, but generally owing their occurrence to desert thunderstorm activity, are delivered far less frequently than those to the Whitewater subregion. Here, massive quantities delivered during the past four years presently await wind transport, held in check to date primarily by extensive surface vegetation. Likely, a new, major wave and barchan-like dune formation similar to that presently situated 2 to 3 km west of Washington Street and 1 to 2 km north of Interstate Highway 10 will evolve. How long this will take is uncertain. It may be several years before recognizable dune forms emerge. Extensive sand veneers and other surficial deposit forms will also be enhanced.

Thus, active transport conditions within the unshielded areas of both subregions appear well assured over the next several years.

Burrows of undetermined origin or present users are relatively abundant throughout the region and at all of the study sites. Aside from the occasional use of such burrows for escape or other periods of inactivity, *Uma* limits itself to activity on the surface and to submergence within the upper few centimeters of aeolian sand deposits (Stebbins 1944, Norris 1958). Submergence, the most common form of retreat from the surface, seldom exceeds 4 or 5 cm. As discussed with Sid England (pers comm), taking the height of the animal itself into account, activity thus appears limited to about 8 cm.

Lastly, the extensive rainfall in recent years has also contributed to the formation of a greater than normal, near-surface crust within most sand deposits and substrates throughout the region. Most prevalent are those formed in deposits where percolation of rainfall is complete, with no evidence of flow along the surface. Finer sediments, silt and clay size particles and minor organic particles are filtered downward, creating an illuvial zone or layer which, when dried, is slightly cohesive. Also, deposits tend to be slightly calcareous, further contributing to the cementing process.

Where formed in wind deposited sands the crusts are generally between 0.5 cm and 2 cm thick and presently exist at or within a few centimeters of the surface. Invariably they are quite fragile, defying removal of pieces larger than a few cm^2. Generally, they disintegrate upon handling. Nonetheless, they quite evidently reduce the ease of penetration of the near-surface deposits on a physical scale probably commensurate with Uma submerging actions. Such conditions were present at all of the study sites.

Where surface runoff occurs, greater concentrations of finer sediments can result in considerably stronger crustal formations such as hardpan or caked orthogonal plates in low-lying areas, as were exhibited at some of the study locations.

Crustal formations induced by rainfall are not uncommon in arid lands (Fletcher and Martin, 1948). Normally, crusts of lesser thickness would exist from time to time at scattered locations throughout the valley. However, personal observations made during studies involving examination of deposits representing several centuries of accumulation at a number of regional locations indicate the present condition to be quite rare, probably not recurring but once in several centuries on the average.

While inhibiting *Uma* submergence activities at and near the surface, the present existence of crustal formations does enhance the creation and maintenance of underlying burrows.

Study Sites

Locations for the 10 study plots were established in early April 1980 following a field review of prospective sites by Fred Turner, Sid England, James Rorabaugh, Russell Duncan and Don Weaver. Final positioning of the 150 m square plots and grid staking at 25 m intervals was done by the biological field personnel engaged in the companion study. In general, the plots were well arrayed over the central portion of the valley, extending from near Garnet Hill, north of Palm Springs, to Washington Street, northwest of Indio, a distance of approximately 24 km. See Exhibit 2, Reference Map.

Plots 5 and 6, 7 and 8, and 9 and 10 were the paired plots. The first member of each pair was an undisturbed area presently subject to natural or near natural aeolian sand transport conditions and deposits, where it appeared that _Uma_ would be present. The second member of each pair was downwind of the undisturbed plot at a location shielded for a known period of time from the natural sand transport process and receipt of sand by a tamarisk tree row obstruction. Each downwind plot was located far enough from the shielding barrier to be exposed to natural or near natural wind conditions. Plots 5 and 7 show on Exhibit 2 as being situated in areas destined for stabilization. However, in each case the present shielding barrier is a considerable distance upwind, as compared with Plots 6, 8 and 10. This condition is discussed later.

Plots 1 through 4 were not a part of the experimental scheme, but were representative of England and Nelson's (1976) sandy hummocks (Plots 1 and 2) and mesquite dunes (Plots 3 and 4). Paired Plots 5 and 6, and 7 and 8 are located in areas representative of their sand Redo plains, with 9 and 10 being representative of sandy hummocks.

Basic plot information is presented in Table 1. Plot 1 is situated at the upwind edge of the basic deposition area and straddles a small swale occasionally subject to surface water flow. The occurrence of such a condition in recent months resulted in dried mudflats covering portions of the plot during the study period. Plates 1 and 2 present on-site and aerial views of the plot. The large, though essentially undeveloped subdivision immediately to the west is Palm Springs Panorama, which has remained basically unchanged since the early 1960's.

Plot 2 is situated in the intermediate transport area of the Indio Hills subregion, and is also subject to occasional surface waters, responsible for present dried clay surface areas. These and hummock deposits less extensive than in Plot 1 are pictured in Plate 3.

TABLE 1

Basic Data and Information

Plot	Direction of sand movement	Mean annual rate at which aeolian sand is received (CY per foot-wide path in the direction of movement): Under natural conditions	Under present conditions	Number of years since receipt of significant quantities of new sand	Mean annual rate of deposition (depth increase in base accumulation): Under natural conditions	Under present conditions	Sand supply source
1	S 49° E	11½	11½	4 (a)	0-0.25mm	0-0.25mm	Whitewater R. floodplain
2	S 36° E	1-	1-	4 (a)	0 (b)	0	Indio Hills alluvial fans
3	S 60° E	2+	2+	0	0 (b)	0	Mission and Morongo washes
4	S 36° E	1+	1+	4 (a)	0 (b)	0	Indio Hills alluvial fans
5	S 42° E	7	7	4 (a)	1.1mm	1.1mm	Whitewater R. floodplain
6	S 40° E	6+	0	7	1.2mm	0	"
7	S 38° E	6+	6+	4 (a)	2.7mm	2.7mm	"
8	S 38° E	6+	0	12	2.7mm	0	"
9	S 71° E	20	20	0	0 (b)	0	"
10	S 66° E	20	0	17	0 (b)	0	"

(a) due to overabundant vegetative cover

(b) deposits are essentially local, induced by vegetation or other obstacles, and overlying water-laid alluvium

Plate 1

Fig. 1. Plot 1. Viewed toward the northwest. Typical lee hummock deposit and responsible verdant creosote in foreground.

Fig. 2. Plot 1. Looking southeast in the direction of sand transport. Windward hummocks shown, with intervening sandy substratum and vegetation.

Plate 2

Fig. 1 . Plot 1. Typical mudflats, dried polygonal plates of fine silt and clay partially covered by blown sands.

Fig. 2. Plot 1. Nov. 1974. Relationship of plot to surrounding terrain. This and all succeeding circles are approximately 350 m. diameter, 2+ times the 150 m. square plot centered within.

Plot 3, featured on Plates 4 and 5, and Plot 4, shown on Plates 6 and 7, differ from the remaining plots from the standpoints of greater abundance of vegetation and generally finer deposits. In addition, these two plots exhibit vertical relief of up to 10 m or more as compared to a maximum of less than 3 at any of the other study sites. These differences are largely due to the existence of the mesquite shrubs. In Plot 4 these shrubs may have been more extensive in the past than at present, as indicated by numerous dead remnants.

Plot 3 presently contains the most extensive vegetation-induced deposits. As noted, this plot is situated on the Banning Fault (of the San Andreas fault system), termed a "vegetation scarp" by Proctor (1968) in reference to near-surface fault-dammed ground water which has caused vegetation to grow in abundance along the fault trace. This appears most markedly on Exhibit 2 and on Plate 5, Figure 1. Plot 3 lies in a small, topographically isolated area commonly referred to as Seven Palms Valley, just outside the area of major aeolian sand transport activity as defined by Weaver (1979). A more or less continuous chain of aeolian deposits interconnect the areas.

Conditions associated with Plot 4, abundant vegetation, rolling mesquite dunes with vertical relief of some 10 m or more, and some dead mesquite,

Fig. 1. Plot 2. Typical lee hummock deposits, viewed toward the northwest. Intervening sandy substratum and vegetation in foreground.

Fig. 2. Plot 2. Looking west. Intervening substratum partially overlain with water borne clayey sediments. Also see Plate 7, Fig. 1.

Plate 4

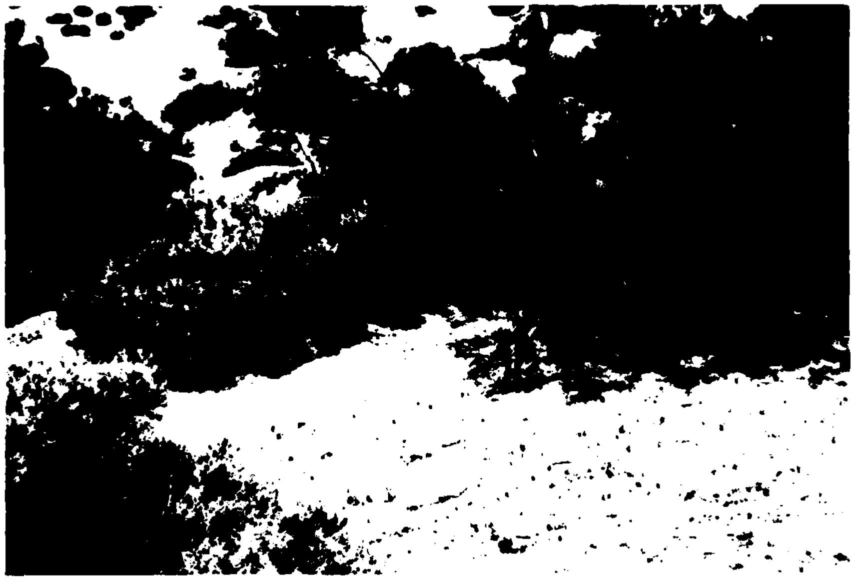

Fig. 1. Plot 3. Viewed toward the south. Mesquite and related deposits in foreground right, with vertical relief reflected in upper left.

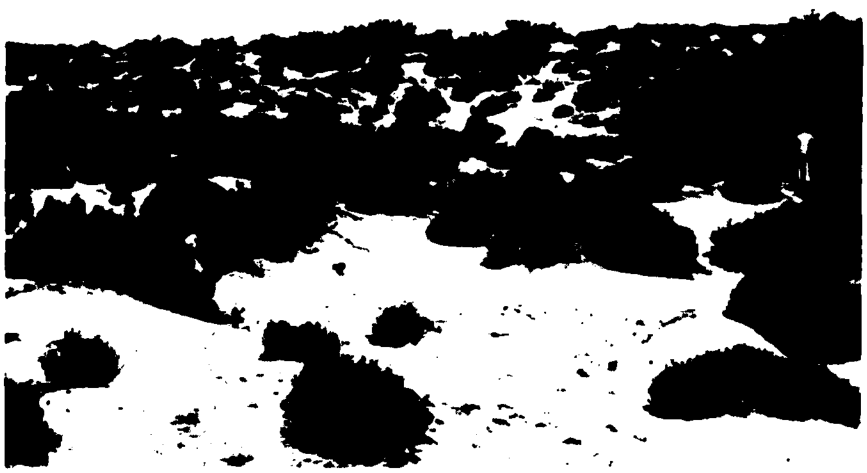

Fig. 2. Plot 3. Looking north. Relative abundance of vegetation.

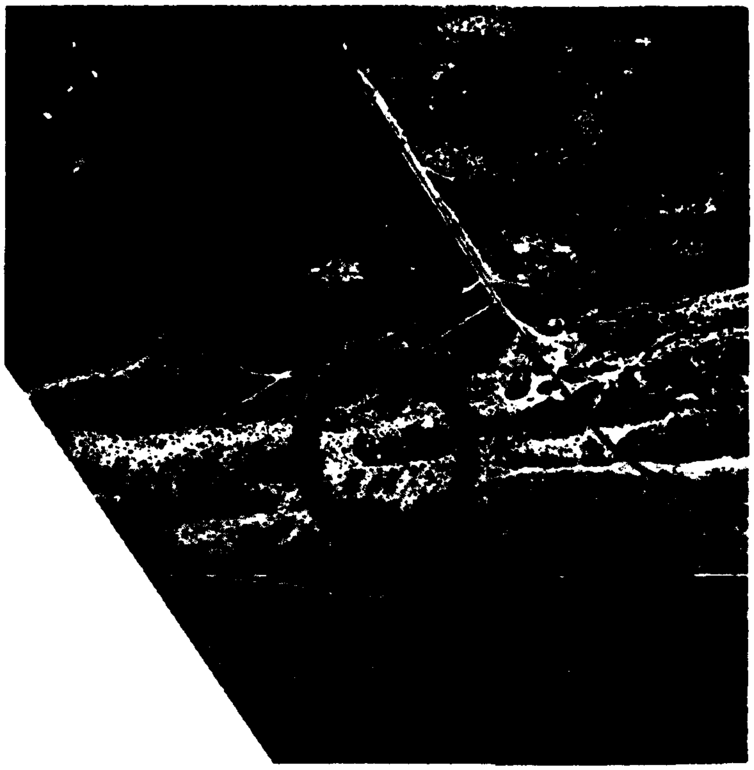

Fig. 1. Plot 3.
Aug. 1979. Relationship and vegetation comparison with surrounding terrain.

Fig. 2. Plot 3.
Enlargement of above.

Plate 6

Fig. 1. Plot 4. Relative abundance of vegetation and intervening sandy substratum, looking toward the northwest. Dead mesquite in foreground.

Fig. 2. Plot 4. Viewed toward the southeast. Russian thistle, dead mesquite, and windward type deposits.

Plate 7

Fig. 1. Plots 4 and 2. March 1960. Relationships with surrounding terrain.

Fig. 2. Plot 4. Enlargement of above.

are pictured on Plate 6, Figures 1 and 2. This was the only plot containing Russian thistle (Salsola kali), but which is even more abundant in the more southeasterly portion of the valley. The general relationship of Plots 2 and 4 is depicted in Plate 7, Figure 1, with an enlargement of the Plot 4 area provided in Figure 2.

The apparent similarity of paired plots 5 and 6 with respect to biological and aeolian sand transport characteristics in 1950, prior to establishment of an intervening barrier is reflected in Plates 8 and 9, and again 10 years later in Plates 10 and 11. Despite not being readily discernable on 1979 aerial photos, Plate 12, marked visual differences now exist on the ground as exhibited by Plates 13 and 14.

Although not as evident as depicted in Plate 12, Figure 2, some minor ORV or other human disturbance was observed at all plots. None appeared to be recent or likely to have caused any significant change in Uma abundance or the sand characteristics studied.

Plate 15, Figure 1, is a panorama of the central portion of the valley showing the relative positions of Plots 1, 5 , and 6.

Surface and deposit conditions for Plots 7 and 8 are shown in Plates 16 and 17. Plates 18 and 19 reflect the general environmental similarity of the two paired plot locations prior to shielding of Plot 8.

Plate 8

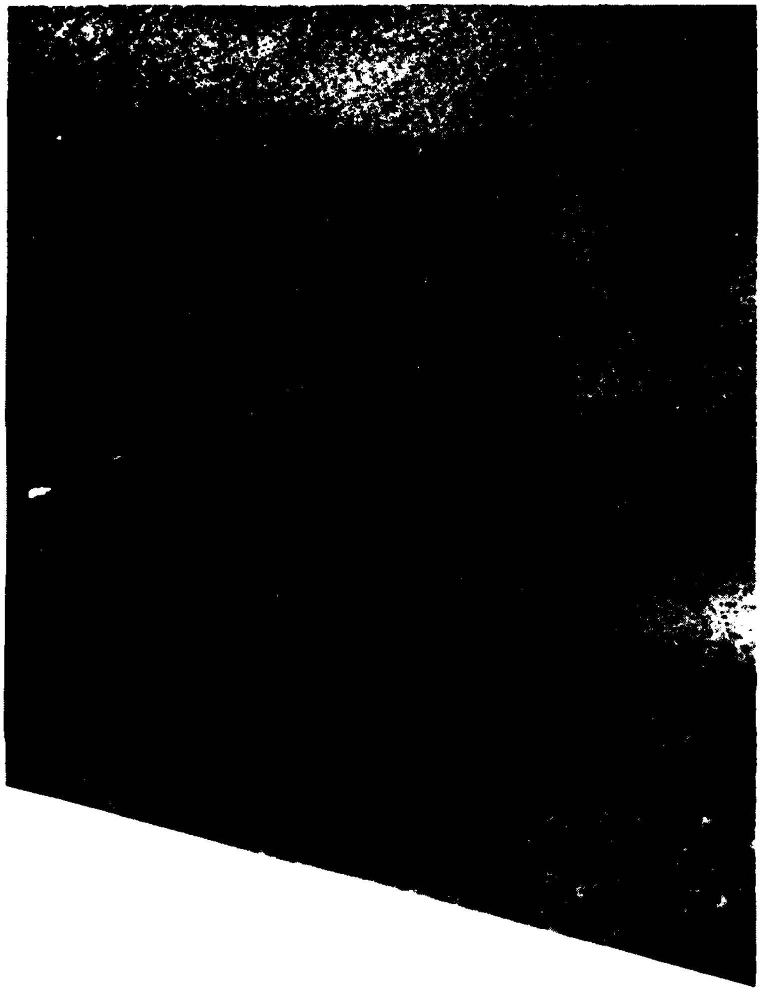

Fig. 1. Plots 5 and 6. December 1950.
Homogeneity of plots under natural conditions.

Plate 9

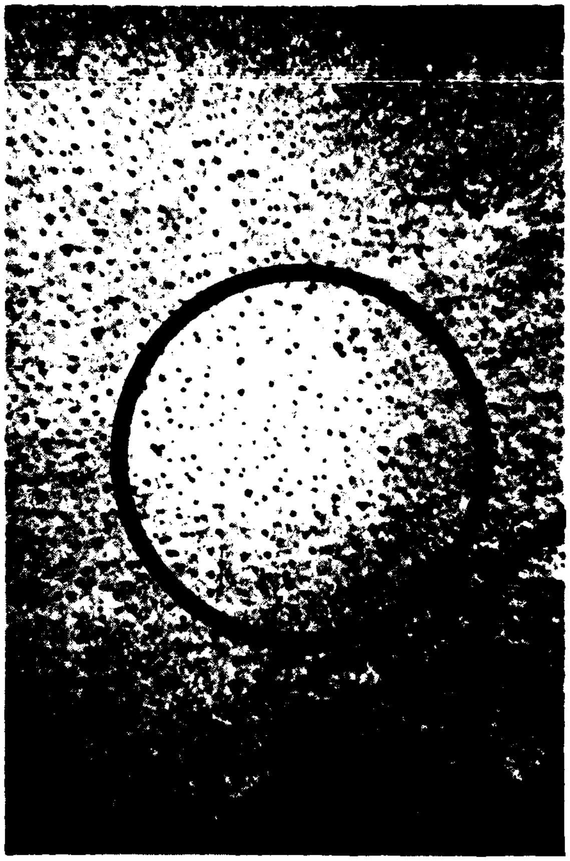

Fig. 1. Plot 5.
Enlargement of Plate 8,
Fig. 1.

Fig. 2. Plot 6.
Enlargement of Plate 8,
Fig. 1.

Plate 10

Fig. 1. Plots 5 and 6. March 1960.

Plate 11

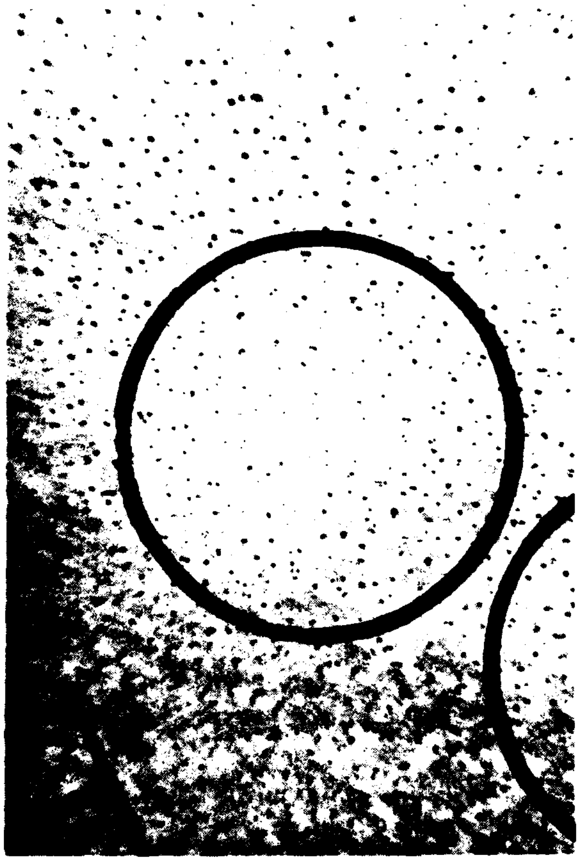

Fig. 1. Plot 5.
Enlargement of Plate 10,
Fig. 1.

Fig. 2. Plot 6.
Enlargement of Plate 10,
Fig. 1.

Plate 12

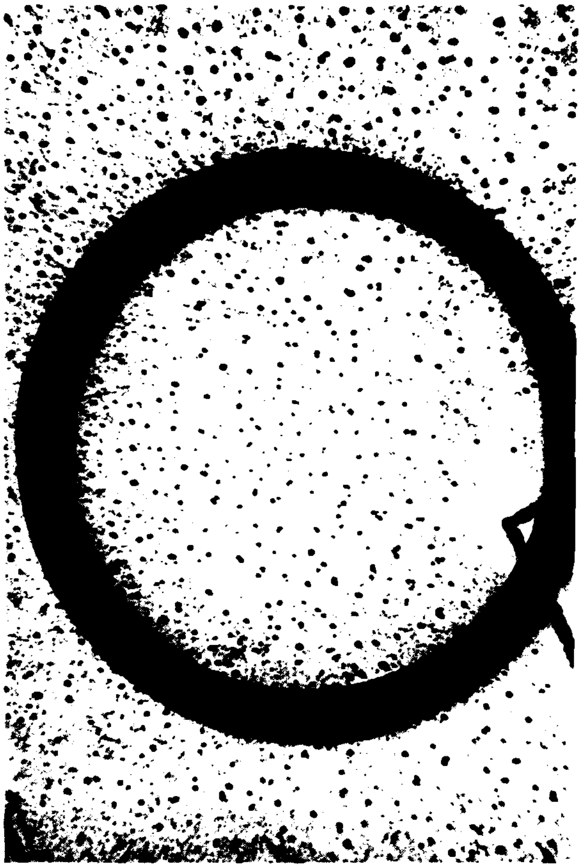

Fig. 1. Plot 5.
Aug. 1979.

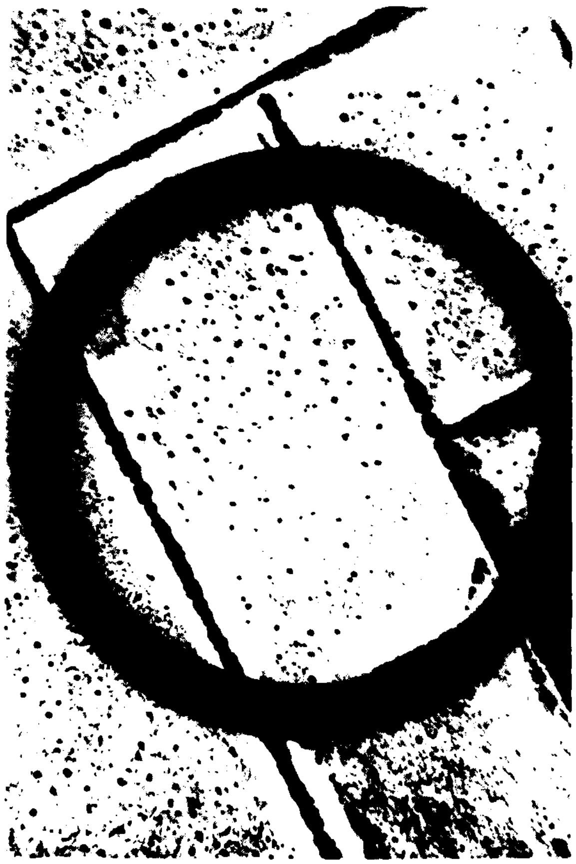

Fig. 2. Plot 6.
Aug. 1979.

Plate 13

Fig. 1. Plot 5. Viewed toward the northwest. Typical lee hummock deposit.

Fig. 2. Plot 5. Looking west at lee hummock deposit, intervening vegetation, and substratum. ORV tracks in foreground.

Plate 14

Fig. 1. Plot 6. Looking east from tamarisk tree induced sand deposit, elevated approximately 15 feet.

Fig. 2. Plot 6. Near total depletion of hummock deposit, the result of seven years without receipt of new sand.

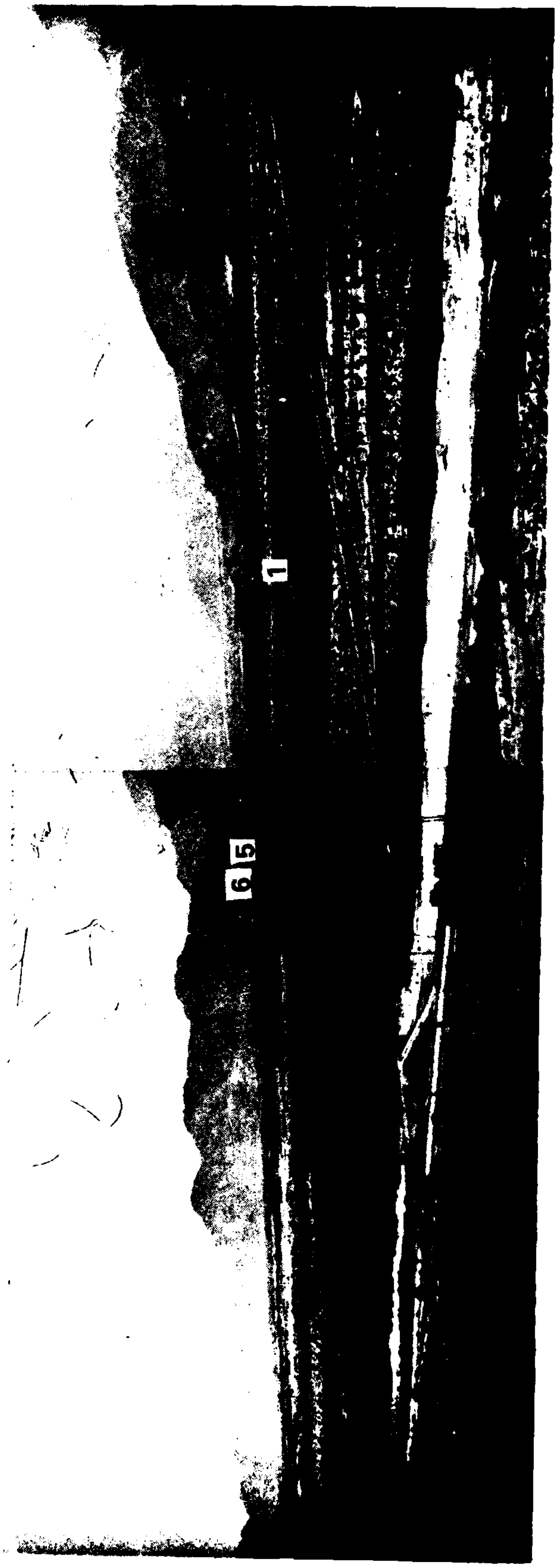

Fig. 1. Panorama of central portion of valley from Flat Top Mtn. Plots 1, 5 and 6 indicated. Dark Surface character due to over-abundance of vegetation and lack of sand transport activity in recent years.

Plate 16

Fig. 1. Plot 7. Typical lee hummock and intervening sandy substratum. Viewed toward the northwest.

Fig. 2. Plot 7. Looking southeast. Windward view of same creosote centered in Fig. 1, above. Barren lower portion reflects prior existance of more extensive hummock deposit. Depletion here has resulted from approximately four years without receipt of new windblown sands.

Fig. 1. Plot 8. More extensive sand depletion than at Plot 7. Complete absence of windward deposit. Tree row in background is downwind of the plot.

Fig. 2. Plot 8. View of same creosote from downwind. Extensive lizard tracks (not Uma) in foreground. Tamarisk tree row shielding this plot from receipt of new sand for approximately twelve years, with resulting deposits, in background.

Plate 18

Fig. 1. Plots 7 and 8. March 1960. Similarity of aeolian sand and biological conditions prior to downwind site being shielded from natural receipt of new sand.

Plate 19

Fig. 1. Plot 7.
Enlargement of Plate 18,
Fig. 1.

Fig. 2. Plot 8.
Enlargement of Plate 18,
Fig. 1.

Extensive hummocks of recently supplied sands in a sand veneer setting found at Plot 9 (Plate 20, Figures 1 and 2) were conspicuously absent at shielded Plot 10, as evidenced by Plates 21 through 23. Plot 10, under natural conditions without the presence of the upwind tamarisk tree barrier would have been subject to similar aeolian sand transport conditions and have displayed the same deposit characteristics. Average diameter of the pebbles comprising the surface shown in Plate 23, Figure 1 is approximately 6.5 mm, representing the upper limit of individual grains movable by the high energy wind regime at this location. The general relationship and similarity of these paired plots is shown in Plates 24 and 25.

Turner et al (1980) lists the more common plants found at each of the ten plots.

Plate 20

Fig. 1. Plot 9. Extensive, freshly supplied hummocks. SPRR tamarisk trees and Garnet Hill in background.

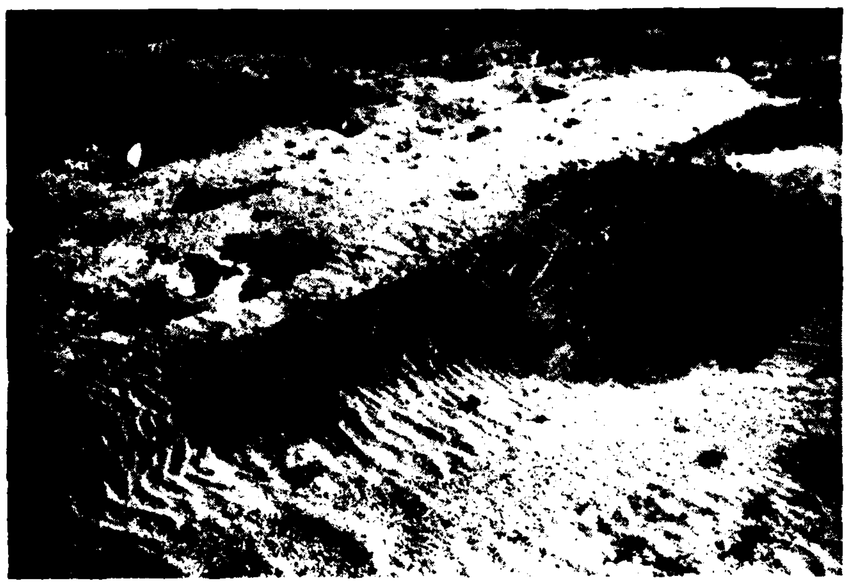

Fig. 2. Plot 9. Difference between finer hummock and coarser intervening deposits. Also, underlying alluvial substratum indicated by rocks.

Fig. 1. Plot 10. Absence of hummock deposit, the result of seventeen years of depletion and surface stabilization without receipt of new sand.

Fig. 2. Plot 10. Northeast portion of plot. Larger rocks, transported by floodwaters thousands of years ago and having remained stationary since, reflect extensive unidirectional sand abrasion.

Plate 22

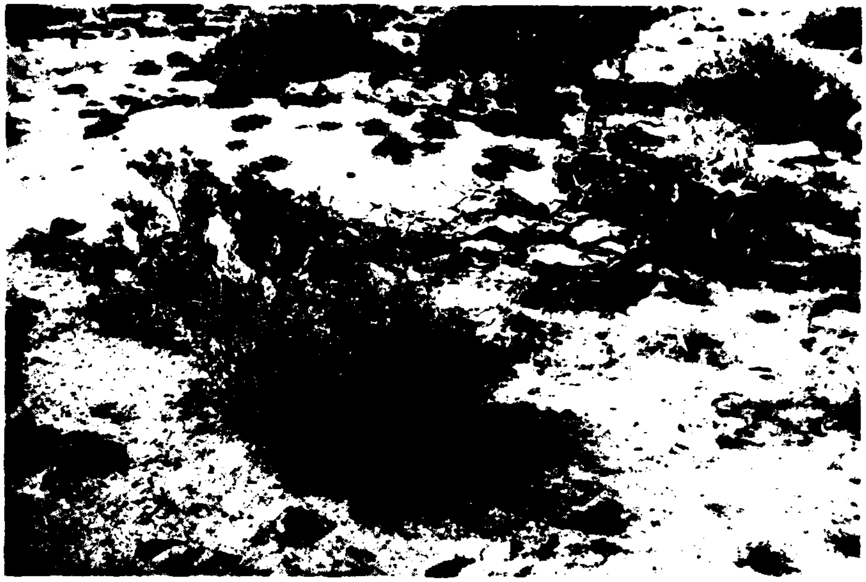

Fig. 1. Plot 10. Coarse, non-sandy substratum. Surface extremely stabilized.

Fig. 2. Plot 10. Miniature hummock deposit. Typical surface character.

Plate 23

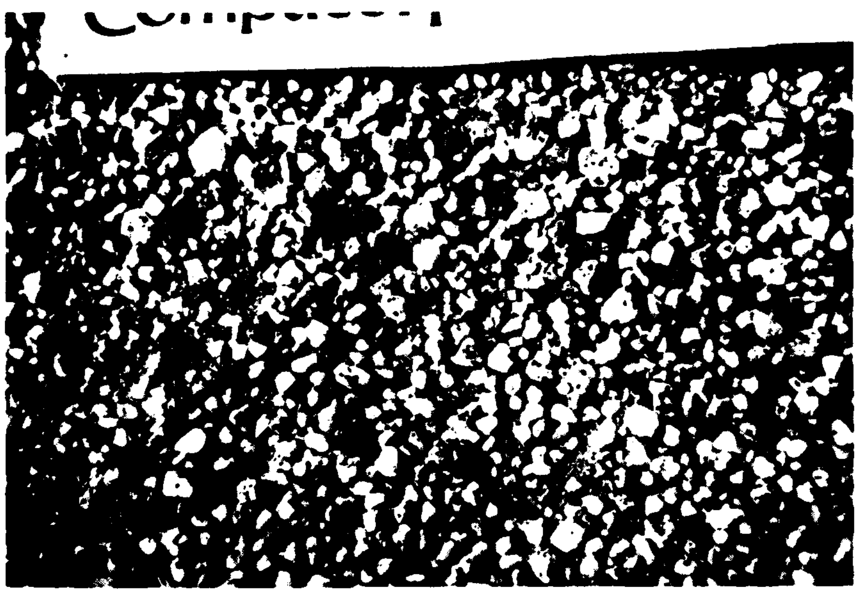

Fig. 1. Plot 10. Closeup of uniform pebbly surface.

Fig. 2. Plot 10. Alluvial rock fragments and aeolian transported sediments comprise a highly stabilized surface. This and the above surface are predominant at Plot 10.

Plate 24

Fig. 1. Plots 9 and 10. Dec. 15, 1950. Basic alluvial character of plots. Apparent equality of aeolian sand transport and biological characteristics. Railroad, running between the plots, was laid in 1879. Comprised only of trackage on a slightly raised bed, it constituted no impediment to aeolian sand transport at the time of this photo.

Plate 25

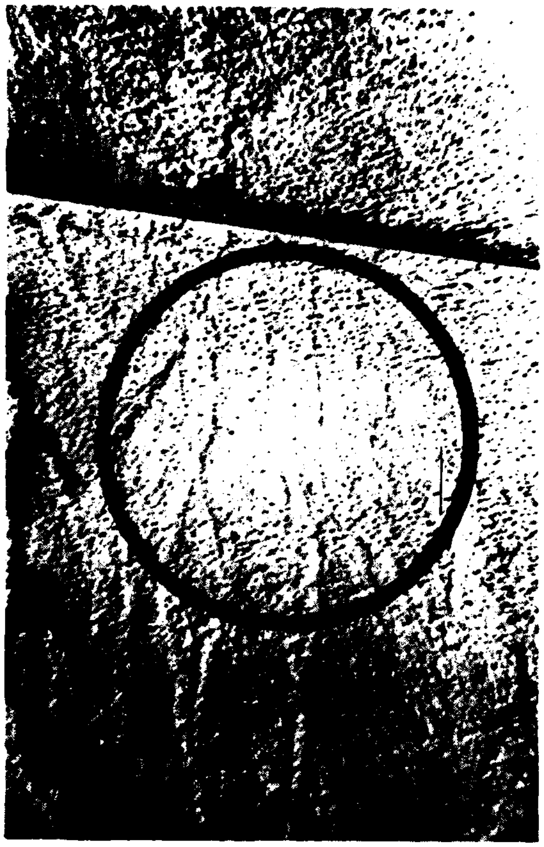

Fig. 1. Plot 9.
Enlargement of Plate 24,
Fig. 1.

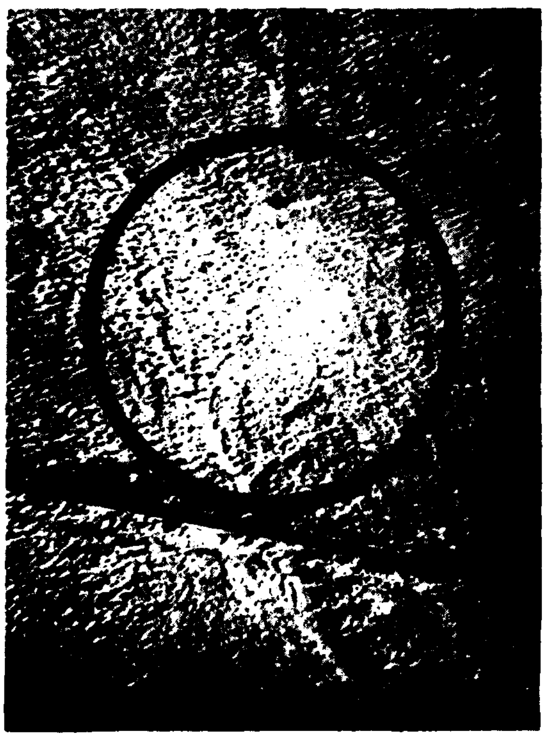

Fig 2. Plot 10.
Enlargement of Plate 24,
Fig. 1.

Tests and Procedures

Three basic textural characteristics of existing sand deposits were examined -- penetrability, size gradation and surface coarseness. Within each plot tests were conducted and samples taken at four locations selected as representative of (1) windward and (2) lee hummock or other vegetation induced deposits, and of (3) average, or most common, and (4) coarsest intervening sandy substrates. Semiquantitative visual estimates were made of the relative area within each plot represented by each of the four sampling locations, plus any non-sandy substrates.

Field work was performed during April and May 1980, with some photographs being taken in June. Climatic conditions were typical for the time of year. Daytime high temperatures ranged from approximately 27°C to above 49°C, with nighttime lows between 0°C and 16°C. No rain fell during the period. For purposes of this study, near-surface deposits could be considered essentially dry during the heat of the day when *Uma* are active, with little or no variation in moisture content throughout the region. Although occasional strong winds occurred, no significant sand transport took place.

Windward hummock test locations were selected directly upwind and approximately 1 m from the vegetation responsible for the deposit. Lee locations were generally selected slightly to the south of center, within 1 to 2 m of the vegetation. Intervening sandy substrate locations were generally situated near the center of relatively open areas where deposition was least influenced by vegetation. Test locations tended to be centrally located within the plots.

Neither Plots 3 nor 10 contained typical windward hummock deposits which could be considered comparable to the remaining plots. Substitute microenvironments were evaluated, as noted in the results.

Penetration tests consisted of releasing a standard 16 oz surveyors' plumb bob* from heights of 30.5 cm (1 ft) and 0 cm (the point just touching the surface before release). Three drops, each into an area not previously disturbed, were made from both heights at each test location. Drops resulting in the plumb bob being tilted more than approximately 20° from vertical were rerun, as were those that occasionally penetrated into theretofore undiscovered burrows. Penetration depths were measured to the nearest 0.1 cm from the tip, along the side of the plumb bob.

Samples were extracted with a closed-end, 6.35 cm diameter cylinder, which was depressed vertically

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* A. Lietz Co., manufacturer; made of brass, with a steel point slightly rounded to a radius of approximately 1 mm, and having a maximum diameter of 3.8 cm located 10.2 cm from the tip.

to a depth of 8 cm. Sand was then scooped away from the side, and the bottom of the cylinder covered with a flat hand-shovel before extraction. At each location, four such samples were taken and combined, providing a total sample weight of approximately 1.5 kg.

The coarsest intervening sandy substratum surfaces were sampled using 3.8 cm wide Scotch clear plastic tape placed over a rectangular, 2.5 cm by 8 cm opening cut in a thin sheet metal plate. Upon being pressed firmly to the surface, the plate was lifted and the tape, with all contacted grains intact, peeled away and transferred to a small card.

Visual estimation of the representative areas within each plot was aided by the 25 m staked grid.

Laboratory and office procedures included penetration tests on the extracted samples, grain size analysis, and measurement of the surface samples. Penetration tests were performed in an attempt to elicit some measure of the influence of the near-surface crust on the field penetration test results. For each sample, any crustal deposits which happened to have survived being extracted and transported were broken up by hand. The sample was then poured slowly into a cylindrical container, 19.5 cm high and 7.75 cm in diameter, the top surface gently leveled, and the sand volume determined by measuring from the top down to the surface to the nearest 0.1 cm. A penetration test was then made from the 30.5 cm height and the result recorded, as in the field. Some consolidation of the sample was then induced by slightly pounding the container down on a hard surface, a determination made of the new reduced volume and another penetration test performed. Yet additional consolidation was induced and the process repeated until a minimum of 4 data sets were obtained. The sample was then transferred to another container and repoured slowly into the test cylinder, and the measurement - test process repeated a minimum of 4 times for the 0 cm drop. The ratios of the consolidated volumes to the loose poured volume were later calculated and these relative volumes plotted against the penetration test results for each of the two drop heights. Curves were drawn through the two sets of points and the penetrations associated with 0.90 relative volume noted. The corresponding field penetration reading was then subtracted from this value and the result recorded as the crustiness index. The relative volume of 0.90 (representing a 10% reduction in volume due to consolidation) was arbitrarily selected as the maximum consolidation that might reasonably be expected to occur under natural conditions in the field. Thus, it was believed that comparison of the field penetrations with those into the same sand at 0.90 relative volume might yield some indication as to the degree of influence the near-surface crust presently in existence has upon the field penetration test results at each location.

Grain size (granulometric) analysis was performed on all 40 samples. Samples, unwashed, were split and sieved in accordance with current American Society for Testing Materials (ASTM) procedures, with U.S. Standard Sieve Sizes of 1/2", 3/8", 1/4", #4, #8, #12, #16, #30, #40, #50, #80, #100 and #200 being used. Results were plotted and cumulative gradation curves drawn using arithmetic scale for percentage finer by weight and log scale for size in mm. More refined analysis involving the use of additional sieves and probability scale in lieu of arithmetic scale, as encouraged by Folk (1966) and others, was viewed as unnecessary for the purpose of this study.

Mean grain size diameter was determined for each sample using the McCammon (1962) formula

$$\underline{d}_{mean} = \frac{\phi_{10} + \phi_{30} + \phi_{50} + \phi_{70} + \phi_{90}}{5}$$

$$\text{with} \quad \phi_p = -\log_2 \underline{d}_p$$

where $\underline{d}_p$ is the grain size in mm at percentile p, as originally proposed by Krumbein (1934).

For comparison with Norris (1958) and Beheiry (1967) data, median grain diameter, or $\underline{d}_{50}$ (being that which has one half the grains, by weight, finer, and one half coarser) was noted directly from the cumulative curve for each sample.

Subsequent anaylses made in conjunction with the companion study solicited examination of diameters associated with other percentiles, with $\underline{d}_{75}$ for the lee deposits eventually found to have significant correlative value (Turner et al. 1980).

Despite more sophisticated techniques now available, for comparison with earlier studies, sorting coefficient, a measure of dispersion around central tendency, was calculated as

$$S_o = \sqrt{\frac{\underline{d}_{75}}{\underline{d}_{25}}}$$

long used as the sorting parameter for sediments (Folk 1966).

Percentages finer than 0.1 mm and coarser than 1.0 mm, noted by Norris (1958), Pough (1970) and England and Nelson (1976) as having correlation with Uma behavior, were taken directly from the gradation curves.

Surface coarseness values were determined as the average of the apparent diameter of the 5 largest grains displayed in each surface coarseness sample. This was accomplished by measuring the apparent length and width of the 8 largest individual grains, as viewed through the clear plastic tape. Measurements were made to the nearest 0.2 mm. aided by 8X magnification. The average of the length and width was considered as the apparent diameter of the grain, with the average of the 5 largest provided as a measure of surface coarseness. Such a measure has precedents with Pettijohn (1957), Schlee (1957), Pelletier (1958) and Towe (1963) using variations in the size of largest pebbles (or averages of several largest) for determining direction and distance of transport of deposited sediments. The maximum size of deposited surface grains bears relationships with the energy of the transporting medium and the depositional environment. When considered in conjunction with underlying average or long-term deposits, it is believed by this researcher to be an indicator of the degree of surface stabilization which has occurred since discontinuance of the normal supply of sand to the transporting winds. The process of surface stabilization has not received sufficient study to suggest a "best" indicator. Nonetheless, for purposes here, a surface stabilization index for each plot was calculated as being the ratio of the apparent diameter of the coarsest surface grains to the average of the mean grain size diameters of the typical and coarsest intervening substrate deposit samples, the average being weighted according to the relative plot area represented.

Lastly, weighted averages were calculated for each plot based upon the relative area represented by each of the 4 microenvironments for all of the test results except the surface coarseness and surface stabilization measures.

Results and Discussion

Basic aeolian sand transport data and information for each of the plots, and area percentages of plots represented by each of the microenvironments are provided in Tables 1 and 2. Tables 3 through 13 present data derived from the various field and laboratory studies described in the previous section. As noted, these data were developed primarily for analysis with the results of the companion biological field study, which are presented here, for convenience, in Table 14 (Turner et al 1980). Clearly, the most important outcome of the combined studies was the difference in *Uma* densities observed in the paired plots, as reflected in Table 14. The significance of these findings is discussed in Turner et al (1980) and further under Shielding in this report.

Overall, data developed in this study are quite consistent with comparable data from earlier reports. Median grain size values (Table 8) compare favorably with those of Norris (1958) and Beheiry (1967). Norris shows diameters of 0.285 mm and 0.120 mm for the finest sands at two locations, the first situated closest to our Plot 5, and the second, with mesquite cited as the predominant vegetation, most closely associated with our Plot 4. Plots 5 and 4 reflect median diameters of 0.22 and 0.14 mm, respectively.

TABLE 2

Area Percentage of Plots by Deposit and Substrate Types

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum
	Windward	Lee	Typical	Coarse	
1	15	30	15	10	30
2	15	10	45	10	20
3	20 [(a)]	45	20	15	--
4	20	40	25	10	5
5	10	20	50	20	--
6	5	10	70	15	--
7	8	17	60	15	--
8	2	8	80	10	--
9	15	30	35	15	5
10	2 [(b)]	1 [(c)]	5	2	90

(a) Beneath mesquite

(b) Hummock lee - coarse

(c) Hummock lee - fine

TABLE 3

Penetrability — 1' Drop Field Test Penetration in Centimeters

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum	Penetrability #2 -- (cm) (Weighted average)	Portion of total plot represented
	Windward	Lee	Typical	Coarse			
1	7.63	9.07	7.00	5.47	--	7.80	70%
2	5.40	5.23	6.00	5.43	--	5.72	80%
3	7.33 (a)	7.70	7.37	6.90	--	7.44	100%
4	5.70	6.97	5.83	5.43	--	6.24	95%
5	7.33	6.43	5.97	6.53	--	6.31	100%
6	7.07	6.93	7.10	5.83	--	6.89	100%
7	5.70	8.80	6.33	7.20	--	6.83	100%
8	7.27	5.70	7.00	6.40	--	6.84	100%
9	5.83	7.07	6.30	5.57	--	6.35	95%
10	5.85 (b)	5.63 (c)	3.93	5.13	--	4.73	10%

(a) Beneath mesquite

(b) Hummock lee - coarse

(c) Hummock lee - fine

TABLE 4

Penetrability — 0' Drop Field Test Penetration in Centimeters

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum	Penetrability #1 -- (cm) (Weighted average)	Portion of total plot represented
	Windward	Lee	Typical	Coarse			
1	4.37	4.47	4.07	2.80	--	4.12	70%
2	2.67	2.13	2.47	3.10	--	2.54	80%
3	4.93 (a)	4.23	4.37	4.27	--	4.40	100%
4	2.40	4.47	2.50	2.60	--	3.32	95%
5	3.00	4.17	2.77	4.83	--	3.49	100%
6	2.80	3.60	3.47	2.63	--	3.32	100%
7	2.53	4.10	2.23	3.90	--	2.82	100%
8	3.60	3.87	3.87	2.87	--	3.76	100%
9	3.83	4.47	3.70	3.23	--	3.89	95%
10	1.27 (b)	1.10 (c)	2.07	2.67	--	1.93	10%

(a) Beneath mesquite
(b) Hummock lee - coarse
(c) Hummock lee - fine

TABLE 5

Crustiness Index — Derived From 1' Drop Penetration Tests

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum	Crustiness Index #2 (Weighted average)	Portion of total plot represented
	Windward	Lee	Typical	Coarse			
1	-1.33	-3.07	-0.70	0.53	--	-1.632	70%
2	0.90	1.07	0.30	0.97	--	0.593	80%
3	-0.33[a]	-1.70	-1.57	-1.00	--	-1.295	100%
4	0.30	0.13	0.37	0.67	--	0.286	95%
5	-0.73	-0.43	0.33	-0.53	--	-0.100	100%
6	-1.47	-1.33	-1.00	0.67	--	-0.806	100%
7	0.50	-2.60	-0.03	-0.90	--	-0.555	100%
8	-0.87	1.20	-0.40	-0.40	--	-0.281	100%
9	0.77	-0.67	-0.20	0.43	--	-0.096	95%
10	-0.15[b]	1.77[c]	2.77	0.47	--	1.622	10%

(a) Beneath mesquite
(b) Hummock lee - coarse
(c) Hummock lee - fine

TABLE 6

Crustiness Index — Derived From 0' Drop Penetration Tests

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum	Crustiness Index #1 (Weighted average)	Portion of total plot represented
	Windward	Lee	Typical	Coarse			
1	0.53	0.63	1.03	1.60	--	0.833	70%
2	2.13	3.17	2.63	1.70	--	2.488	80%
3	1.27[a]	0.67	0.33	0.33	--	0.671	100%
4	2.40	1.23	2.60	3.10	--	2.034	95%
5	1.80	0.23	2.33	-0.33	--	1.325	100%
6	1.80	0.80	0.73	1.87	--	0.962	100%
7	2.67	0.90	2.67	1.10	--	2.134	100%
8	1.60	1.13	1.23	1.63	--	1.269	100%
9	1.37	-0.07	0.80	1.17	--	0.674	95%
10	3.43[b]	3.80[c]	2.03	1.73	--	2.427	10%

(a) Beneath mesquite

(b) Hummock lee - coarse

(c) Hummock lee - fine

TABLE 7

Mean Grain Size Diameter (mm)

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum	Mean Diameter (mm) (Weighted average)	Portion of total plot represented
	Windward	Lee	Typical	Coarse			
1	0.26	0.31	0.34	0.49	--	0.33	70%
2	0.30	0.29	0.29	0.30	--	0.29	80%
3	0.19[a]	0.26	0.36	0.38	--	0.28	100%
4	0.18	0.14	0.22	0.20	--	0.18	95%
5	0.39	0.26	0.42	0.37	--	0.38	100%
6	0.28	0.29	0.28	0.36	--	0.29	100%
7	0.26	0.29	0.33	0.33	--	0.32	100%
8	0.24	0.47	0.29	0.40	--	0.31	100%
9	0.31	0.22	0.33	0.54	--	0.32	95%
10	0.37[b]	0.20[c]	0.13	0.67	--	0.29	10%

(a) Beneath mesquite

(b) Hummock lee - coarse

(c) Hummock lee - fine

TABLE 8

Median Grain Size Diameter (mm)

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum	Median Diameter (mm) (Weighted average)	Portion of total plot represented
	Windward	Lee	Typical	Coarse			
1	0.26	0.37	0.42	0.60	--	0.39	70%
2	0.39	0.35	0.32	0.37	--	0.34	80%
3	0.23[a]	0.27	0.43	0.45	--	0.32	100%
4	0.18	0.14	0.23	0.24	--	0.18	95%
5	0.47	0.22	0.72	0.35	--	0.52	100%
6	0.27	0.31	0.28	0.37	--	0.30	100%
7	0.25	0.32	0.45	0.44	--	0.41	100%
8	0.24	0.63	0.32	0.62	--	0.37	100%
9	0.34	0.22	0.39	0.56	--	0.36	95%
10	0.33[b]	0.17[c]	0.11	0.99	--	0.34	10%

(a) Beneath mesquite

(b) Hummock lee - coarse

(c) Hummock lee - fine

TABLE 9

Sorting Coefficient

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum	Sorting Coefficient (Weighted average)	Portion of total plot represented
	Windward	Lee	Typical	Coarse			
1	1.46	1.70	1.83	2.05	--	1.44	70%
2	2.11	1.82	1.88	1.87	--	1.91	80%
3	1.39[a]	1.73	1.64	1.62	--	1.63	100%
4	1.61	1.22	1.65	1.46	--	1.44	95%
5	2.54	1.96	2.58	2.54	--	2.45	100%
6	2.07	2.22	2.18	2.61	--	2.24	100%
7	1.69	1.66	1.98	2.08	--	1.92	100%
8	1.67	1.21	2.07	2.21	--	2.01	100%
9	1.83	1.48	2.00	2.78	--	1.93	95%
10	2.89[b]	1.86[c]	1.62	3.37	--	2.25	10%

(a) Beneath mesquite
(b) Hummock lee - coarse
(c) Hummock lee - fine

TABLE 10

% (by weight) Finer than 0.1 mm Diameter

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum	% Finer than 0.1mm Diameter (Weighted average)	Portion of total plot represented
	Windward	Lee	Typical	Coarse			
1	6	9	8	5	--	7.6	70%
2	13	10	10	10	--	10.6	80%
3	14[a]	7	9	6	--	8.6	100%
4	16	14	12	12	--	13.7	95%
5	10	10	14	10	--	12.0	100%
6	13	14	14	10	--	13.4	100%
7	9	8	10	10	--	9.6	100%
8	11	6	13	12	--	12.3	100%
9	8	8	12	7	--	9.3	95%
10	13[b]	18[c]	31	12	--	22.3	10%

(a) Beneath mesquite
(b) Hummock lee - coarse
(c) Hummock lee - fine

TABLE 11

% (by weight) Coarser than 1.0 mm Diameter

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum	% Coarser than 1.0mm Diameter (Weighted average)	Portion of total plot represented
	Windward	Lee	Typical	Coarse			
1	1	3	3	28	--	6.1	70%
2	2	2	1	1	--	1.3	80%
3	0 [a]	1	3	6	--	2.0	100%
4	0	0	0	0	--	0	95%
5	23	4	24	24	--	19.9	100%
6	5	3	7	24	--	9.0	100%
7	2	3	3	4	--	3.1	100%
8	2	3	3	9	--	3.6	100%
9	6	0	9	40	--	10.6	95%
10	29 [b]	6 [c]	6	50	--	19.4	10%

(a) Beneath mesquite
(b) Hummock lee - coarse
(c) Hummock lee - fine

TABLE 12

Surface Coarseness -- Apparent Diameter of Coarsest Surface Grains (mm)

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum	Portion of total plot represented
	Windward	Lee	Typical	Coarse		
1	--	--	--	3.00	--	10%
2	--	--	--	1.66	--	10%
3	--	--	--	3.26	--	15%
4	--	--	--	1.36	--	10%
5	--	--	--	3.10	--	20%
6	--	--	--	3.18	--	15%
7	--	--	--	2.08	--	15%
8	--	--	--	2.18	--	10%
9	--	--	--	2.86	--	15%
10	--	--	--	8.00	--	2%

(a) Beneath mesquite

(b) Hummock lee - coarse

(c) Hummock lee - fine

TABLE 13

Surface Stabilization Index

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum	Surface Stabilization Index	Portion of total plot represented
	Windward	Lee	Typical	Coarse			
1						7.50	
2						5.69	
3						8.84	
4						6.35	
5						7.64	
6						10.81	
7						6.30	
8						7.21	
9						7.28	
10						28.14	

(a) Beneath mesquite

(b) Hummock lee - coarse

(c) Hummock lee - fine

TABLE 14

Observed *Uma inornata* Densities[a]

Plot	Density estimate ($n \cdot ha^{-1}$)
1	17.2
2	16.8
3	8.8
4	45.5
5	4.4
6	0
7	43.0
8	0.4
9	45.0
10	0

(a) source: Turner et al (1980)

Beheiry sampled four locations (his Sites 2, 5, 8 and 11) displaying median diameters of 0.35 mm, 0.40 mm, 0.20 mm and 0.38 mm, by description comparable to our typical intervening sandy substrates which exhibit an overall average median diameter of 0.37 mm. His comparable lee deposits (Sites 1, 4, 7, 10 and 12) ranged from 0.11 mm to 0.27 mm, ours from 0.14 mm to 0.37 mm (excluding Plot 8 which was 0.63 mm). Here, in making such grain size comparisons, it is important to note that the present data probably reflects a greater recent stabilization, deposit coarsening process than the earlier measurements, particularly in the shielded plots.

Sorting coefficients, shown in Table 9, likewise agree closely with Norris (1958), 1.94 and 1.37 for his locations cited previously, as compared with the present 1.96 and 1.22. The same is true for Beheiry's lee and intervening substrate deposits which for the Sites noted averaged 1.63 and 2.26 versus our 1.69 and 1.94.

Deposit characteristics varied widely within each plot, to the extent that for every characteristic measured at the four microenvironments within each of the plots, a range existed which was common to all plots. For example, mean grain diameter (Table 7) ranged overall from 0.13 mm to 0.67 mm at various of the microenvironments within the plots. However, all plots contained some deposits displaying a mean diameter in the range of 0.22 mm to 0.29 mm (either as measured directly, or as inferred through measurements both above and below this range). The same is true for Penetrability, for the 1' drop (Table 3) between 5.85 cm and 6.90 cm, and the 0' drop (Table 4) between 2.67 cm and 4.23 cm; for the Crustiness Index, 1' drop (Table 5) between -0.33 cm and 0.30 cm, and 0' drop (Table 6) between 1.27 cm and 1.73 cm; for Median grain diameter (Table 8) between 0.24 mm and 0.32 mm; for Sorting Coefficient (Table 9) between 1.65 and 2.07; and % Finer than 0.1 mm Diameter and % Coarser than 1.0 mm Diameter (Tables 10 and 11) between 9% and 12%, and 0% and 6%, respectively.

Thus, despite visually obvious overall differences between most of the plots in the field, differences in individual textural characteristics of the deposits are quite subtle. In fact, if one were to assume that normal conditions existed at each of the plots, and taking plot locations within the region into account, inconsistencies abound relative to every characteristic studied, particularly among data relating to vegetative induced deposits. Under normal conditions, windward hummock deposits would consistently be less penetrable and comprised of a coarser distribution of grains than lee deposits. However, data in Tables 3, 4, 7, 8, 10 and 11 do not conform. Similarly, deposits nearer the northwestern, source end of the region would normally be coarser than those extending progressively to the southeast. In other words, Plot 9 should exhibit coarser deposits than Plot 5, and Plot 5 coarser than Plot 7. Again, data in Tables 7, 8, 10, 11 and 12 do not bear this out. Likewise, under natural conditions paired plots should exhibit essentially the same characteristics. Previously described effects of reduced or discontinued receipt of new sand for varying time periods offer a plausible explanation for the values in characteristics found.

In Turner et al (1980) no significant correlations were found between individual aeolian sand transport and deposit characteristics and the observed *Uma* densities. However, more detailed analyses, involving combinations of characteristics, elicited several highly significant relationships. Specific lee deposit characteristics, coarseness of intervening sandy substrate surfaces and years of stabilization, in combination, appear to most significantly influence *Uma* abundance. Appropriate mathematical models for predicting *Uma* densities based upon these variables are presented in the companion study.

Shielding

Shielding, as used here, describes the condition which prevails once the natural transport of sand into an area is discontinued by the artificial emplacement of a barrier to the natural transport process. Although similar to the effects of gradual depletion of source supplies previously described, the effects of shielding on near-surface deposit characteristics beyond the area shaded from wind by the barrier itself occur more rapidly and are more pronounced due to the relatively abrupt discontinuance of sand being fed into the area.

Weaver (1979) indicates that the shielding effects of any substantial barrier to the natural transport of sand will, in time, extend to the downwind end of the region because of the extreme unidirectional nature of the sand movement pattern. A substantial barrier is intended to imply one which extends a few hundred meters or more laterally across the path of movement and has the capability of dealing with the quantities of sand intercepted over a reasonably long period of time.

Effects upon near-surface deposit characteristics are essentially those resulting from winds, unladen with sand, scouring existing surfaces until all susceptible wind-transportable particles have been redistributed sufficiently far downwind that they are no longer susceptible to further movement by the diminishing wind regime. Effectively, within intermediate transport areas, this leads to eventual elimination of virtually all sand deposits and, within the basic deposition area, to the eventual near complete depletion of hummock deposits and stabilization of intervening sandy substrate surfaces.

How rapidly does this sand depletion - surface stabilization process occur? And what are the effects upon the quality of Uma habitat? Prior to the present study, little data was available to aid in answering these questions. Based upon extremely meager data, Weaver (1979), at the request of the Corps of Engineers, suggested downwind progression rates of 3/4 mile per year between Indian Avenue and Vista Chino and 1/4 mile per year beyond Vista Chino to Ramon Road. Further, these rates were intended to reflect the near complete elimination of sand transport and may or may not be representative of the effects upon Uma habitat or abundance.

In general, sand depletion and surface stabilization occur more rapidly under the more intensive wind regime in the upper portion of the valley. Likewise, the process occurs more rapidly immediately beyond the wind-shaded area behind a given barrier than it does farther downwind. Within the area shielded from wind by barriers of a vertical nature (that area situated immediately behind the barrier and extending approximately 10 times the height of the barrier in the downwind direction), the sand depletion process is retarded. Thus, surface stabilization is essentially complete once the barrier is in place.

Insofar as possible, shielded members of the paired plots (Plots 6, 8 and 10) were purposely located just beyond the wind-shaded areas, to test the most rigorous effects of the sand depletion-surface stabilization process associated with the related barriers. The number of years since emplacement of the barrier was 7, 12 and 17, respectively for the 3 plots, as indicated in Table 1.

Natural and shielded states of the surficial deposit forms can readily be noted in the field, particularly in such contrast as exhibited by the paired study sites.

Clearly, the effects of shielding are detrimental to the existence of *Uma*, as reflected by the results of the biological field counts shown in Table 14. In all three plots the effected changes in aeolian sand characteristics, and possibly in related biological variables, have effectively rendered the area unsuitable as *Uma* habitat. These findings strongly suggest that *Uma* population will eventually be extinguished in all areas shielded from the natural receipt of windblown sand.

To preliminarily assess the importance of this condition it was decided late in the study to map the presently developed or shielded areas, which are indicated in Exhibit 2. Excluding the source areas west of Indian Avenue and along the base of the Indio Hills, approximately 80% of the region is presently either developed or shielded. Area determinations show this condition to apply to 24 km^2, or 49% of the intermediate transport area and 91 km^2, or 95% of the basic deposition area within the Whitewater subregion, and to 17 km^2, or 60% of the intermediate transport area and 78 km^2, or 97% of the basic deposition area within the Indio Hills subregion.

It can be noted that Plots 1, 2, 5 and 7, all of which support Uma populations, are also located within shielded areas. This was not taken into account in the present studies due to the distances from the shielding barriers involved and the seemingly more important influence of 4 years of surface stabilization induced by the recent overabundance of vegetative cover. Similarly, observations by England and Nelson (1976) indicated at least some presence of Uma in shielded areas, including locations more than 8 km south of Indio, deprived of any significant new deposits for many years. They did not, however, detect presence southerly of State Highway 231, the extent previously recorded.

Of final note regarding shielding is that elimination of a barrier, either through removal or its being impounded to capacity, renews the natural sandflow into the previously shielded area, eventually resulting in restoration of the natural sand transport environment.

Concluding Remarks

Results of the present studies considered in light of anticipated sand transport activity in areas which remain subject to the natural aeolian sand transport process suggest the favorable continuation, and possible enhancement of Uma habitat quality over the next several years. Conversely, the now verified effects of shielding project a discouraging picture for those shielded areas still supporting significant Uma population, as well as for areas destined for shielding by anticipated continuing land development. From the standpoint of preserving the species, emphasis should be placed upon preserving areas in an unshielded state.

Models presented in the companion study will now permit, with minimal field work, prediction of Uma densities at other sites within the region, facilitating population estimates over selected areas.

Pointed out is the need for further studies into the effects of shielding and the habitat degradation and population declination processes, in terms of time, proximity and location within the valley. This will allow more definitive assessments of future habitat and population changes within presently shielded areas, of the potential effects of proposed shielding-oriented projects, and of habitat enhancing concepts.

Appropriate biological field studies should be integral to all such efforts. Also included should be examination of other biological variables, which were essentially excluded from the present studies.

England and Nelson (1976) performed extensive areal analyses of the Redo overall Uma habitat situation in view of the then existing and anticipated future development the valley. Results of the present study strongly urge an updating of their work, with the now verified effects of shielding taken into account.

It is indeed a pleasure to engage in studies which so closely link the biological and physical sciences.

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