APR 8 1968

MASTER

Final Report
(COO-1336-6)

for

Grant No. AT(11-1)-1336

Title

Reaction of Native Animals Living in the Vicinity
of an Underground Nuclear Detonation

by

Clive D. Jorgensen
March 1, 1968

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

LEGAL NOTICE

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Preface

The following is a report of the work completed on Grant No. AT (11-1)-1336 from the United States Atomic Energy Commission to the Department of Zoology and Entomology, Brigham Young University, Provo, Utah. This is submitted as a final report to complete the obligation of Brigham Young University to the USAEC for this grant.

Numbered (USAEC) Reports Contributing to this Final Report

- COO-1355-8: Mammals of the Nevada Test Site. Brigham Young Univ. Sci. Bull. Biol. Ser. 6(3): 81 pp. 1965. Clive D. Jorgensen and C. Lynn Hayward.
- COO-1355-13: A Summary of the Ecological Effects of Nuclear Testing on Native Animals at the Nevada Test Site. Proc. Utah Acad. Sci., Arts and Letters 42(2): 252-260. 1965. Donald M. Allred, D Elden Beck, and Clive D. Jorgensen.
- COO-1336-1: Home Range as a Measure of Probable Interactions Among Populations of Small Mammals. J. Mammal. 49(1): in press. 1968. Clive D. Jorgensen.
- COO-1336-2: Small Mammal Invasion of a Trapped-out Habitat. (Master's Thesis, Brigham Young University); 35 pp. 1966. Lester D. Flake.
- COO-1336-3: A New Species of Tuckerella (Acarina: Tuckerellidae) from Nevada. Entomol. News 78(6): 141-146. 1967. Clive D. Jorgensen.
- COO-1336-4: Determining a Reliable Estimate of Home Range for Small Mammals (Master's Thesis, Brigham Young Univ.); 39 pp. 1967. John R. Burge.

COO-1336-5: Effects of Nuclear Weapons Testing on Natural Populations of Small Mammals (Manuscript in preparation). Clive D. Jorgensen.

COO-1336-6: Reaction of Native Animals Living in the Vicinity of an Underground Nuclear Detonation (Final Report to USAEC). Clive D. Jorgensen.

Table of Contents

	Page
1. Determining a Reliable Estimate of Home Range for Small Mammals	1
1.1. Introduction	1
1.2. Field Methods and Descriptions	3
1.3. Statistical Methods	3
1.4. Application of the Box and Cox Transformation	9
1.5. Home Range Estimates of <u>Perognathus longimembris</u>	11
1.6. Determination of Sample Size	20
1.7. Determination of Sample Time	20
1.8. Summary and Conclusions	23
2. Home Range as a Measure of Probable Interactions Among Populations of Small Mammals	25
2.1. Introduction	25
2.2. Methods	26
2.3. Application to Data	36
2.4. Discussion	37
3. Spatial Relationships of a Population of <u>Perognathus longimembris</u>	40
3.1. Introduction	40
3.2. Methods	40
3.3. Results	41
3.4. Discussion and Conclusions	48
4. Small Mammal Invasion of a Trapped-out Habitat	49
4.1. Introduction	49
4.2. Description of the Study Area	50
4.3. Field Methods	50
4.4. Analysis Methods	52
4.5. Results	54
4.6. Discussion	67
5. Reactions of Small Mammals to an Underground Nuclear Detonation	76
5.1. Introduction	76
5.2. Procedures	76
5.3. Vegetation Analyses	77
5.4. Small Mammal Trapping Procedures	77
5.5. Results of Vegetation Analyses	78
5.6. Results of the Small Mammal Trapping	80
5.7. Discussion	89
6. Some Effects of an Underground Nuclear Detonation on Certain Invertebrates	102
6.1. Introduction	102
6.2. Methods	102
6.3. Results	102
7. Conclusions - - - - -	109
8. Literature Cited - - - - -	109

Overall Objectives

The objectives of this study were (1) to determine the kinds and populations of small mammals and selected groups of arthropods and the rate which they reinhabit an area affected by a nuclear detonation, and (2) to determine the migrality of small mammals into and away from the disturbed area. These objectives assume that reasonably reliable measurements can be taken of the populations concerned, as well as reliable estimates of the interactions among members in the populations and how these interactions are affected by changes in the environment, such as the changes brought about by a nuclear detonation. These assumptions have been examined and the results used to interpret the data gathered for the nuclear detonation "Sedan".

The final report is divided into eight sections, each presents a logical sequence of data and information that are useful in interpreting the results obtained before and after the nuclear detonation.

1. Determining a Reliable Estimate of Home Range for Small Mammals

1.1. Introduction

In order to study the population biology of small mammals, methods have been developed to measure the area over which an animal habitually travels during its normal activities. This area is referred to as the home range.

The concept of home range is a useful biological phenomenon in the ecology of animal populations (Tinkle, McGregor and Dana, 1962; Calhoun and Casby, 1958; Dice and Clark, 1953; Hayne, 1949). The

methods which have been used to measure home range are diverse, and all have inherent problems which are biologically unrealistic. Hayne, 1949, stated that an understanding of the biological significance of home range must include a knowledge of the intensity to which the various parts of a range are used by an animal. Unequal use of areas within a home range may be the result of several factors operating in the environment (availability of food, basking areas, cover, and perhaps competition). This unequal use was later defined as a density probability function by Dice and Clark (1953) and Jorgensen and Tanner (1963). Calhoun and Casby (1958) examined the methods of estimating density with particular reference to the role of home range in making such estimates more logical and precise.

The usefulness of the home range concept was limited before 1949 due to the difficulty in measuring the amount of area included. Hayne (1949) reviewed the various methods used for calculating home range, and introduced the concept of a center of activity¹ and considered the probability of an animal being present at various distances from this center. Examining Hayne's idea, Dice and Clark (1953) developed a method for estimating the probability associated with any specified distance from this reference point.

Dice and Clark (1953) applied their ideas to a set of trapping records of the prairie deer mouse (Peromyscus leucopus (Rafinesque)). The transformation $\underline{r}' = (\underline{r} + \frac{1}{2})^{\frac{1}{2}}$ was applied to each of the 185

¹The center of activity is the geometric center of all activity loci--the activity locus being one of an infinite number of points that may be occupied by an animal in moving within its home range (Hayne, 1949).

capture radii ($\underline{r}$)¹. Fisher's g statistics were applied to the transformed variable ($\underline{r}'$). When the results indicated departure from normality, an attempt was made to fit $\underline{r}'$ to the Pearson type III distribution. Consequently, the probability of a randomly chosen $\underline{r}'$ exceeding a specified value was estimated by using the standard variate of the Pearson type III distribution.

Accordingly, Dice and Clark (1953) performed a chi-square test of goodness of fit on the transformed variate. With 15 class intervals of recapture radii there resulted a chi-square of 20.28. The hypothesis of a Pearson type III distribution was rejected at the 5% level.

The principle objectives of this action were (a) to derive a reliable² estimate of home range by extending the statistical treatment given by Dice and Clark (1953); (b) to seek a more precise and a more direct method for estimating the probability associated with any specified distance from the center of activity; (c) to determine the number of recapture radii required in order to assert with a degree of confidence γ that α of the activity radii for a given animal will not exceed a certain value; and (d) to determine the trapping time required in order to acquire a specified number of recapture radii.

1.2. Field Methods and Descriptions

¹The recapture radius ($\underline{r}$) is the distance between a recapture locus and the recapture center--the recapture center being an estimate of the center of activity. The recapture center is the geometric center of all the recapture loci--the recapture locus being one of a finite number of points at which an animal was captured.

²The reliability of the system is the probability that the system will accomplish its designated purposes.

Data for the movements of the least pocket mouse (Perognathus longimembris (Coues)) were obtained from trapping records secured in the summer of 1964 on the United States Atomic Energy Commission Nevada Test Site. A grid of traps was established in a Lycium pallidum association of the Larrea-Franseria biotic community described by Allred, Beck and Jorgensen (1963). The grid had about 11.9% total plant cover which consisted of 60.0% Lycium pallidum, 17.4% Grayia spinosa, 8.2% Lycium andersonii, 7.0% Dalea polyandena, 2.7% Eurotia lanata, 2.7% Atriplex canescens, and 2.0% Artemisia spinescens, Atriplex confertifolia, Mirabilis pudica, and Oryzopsis hymenoides.

The grid contained 12 transects spaced 22.9 m apart, and arranged so they formed 121 squares within the grid. This provided a 12 x 12 grid covering 6.35 ha with 144 stations.

Three Young type small mammal traps were placed at each station and baited with rolled oats. To avoid the possibility of some individuals developing "trap happiness," the traps were moved to alternate locations around the stations on a randomized schedule so that they were at one location for a maximum of three consecutive days. The alternate locations were mid-way between adjacent stations and all traps were moved on the same day so the distance between traps remained constant (22.9 m) even though they weren't located precisely on the stations. This provided three alternate locations for each station. The grid was operated continuously for 30 days (June 11 to July 10, 1964). Captured animals were given an identification mark and the following additional data recorded: recapture number, position of recapture, and sex.

1.3. Statistical Methods

For each recaptured animal the recapture center and the distance $\underline{r}$ of each capture from this center was calculated. Frequency histograms of the recapture radii demonstrated an unusually large number of radii in the upper tail (Fig. 1.1 and 1.2). Positions of recapture for the animals with radii exceeding 21.3 m were examined, and an attempt was made to justify removing those which were exceedingly large. This check revealed that in each case the animal had been captured far outside the area over which it had normally traveled. These extended forays were omitted from the data and new recapture radii computed. The 821 remaining recapture radii obtained in this fashion resulted in 480 recapture radii for females and 341 recapture radii for males.

This study assumes that the probability of an animal being in a particular region of the home range depends upon the distance between the recapture locus and the animal's center of activity. One method for estimating this probability was developed by Dice and Clark (1953). They selected one animal and computed the probability that a random capture will exceed a distance $\underline{r}_0$ from the animal's recapture center.

The present study has examined an alternate method for calculating the probability that a randomly chosen $\underline{r}$ will be less than some specified value determined from the data. The procedure is to pool all of the recapture radii obtained, and to find a transformation $\underline{T}$ that will produce a normally distributed random variable $\underline{r}^i$ when applied on the several recapture radii. Computations are based on the following formulae:

$$\underline{Tr} = \underline{r}^i \quad (1.1)$$

Frequency Distribution

Class	Class Boundaries	Class Frequency
1	0 < $\underline{r}$ $\leq$ 5	52
2	5 < $\underline{r}$ $\leq$ 10	106
3	10 < $\underline{r}$ $\leq$ 15	126
4	15 < $\underline{r}$ $\leq$ 20	72
5	20 < $\underline{r}$ $\leq$ 25	55
6	25 < $\underline{r}$ $\leq$ 30	43
7	30 < $\underline{r}$ $\leq$ 35	12
8	35 < $\underline{r}$ $\leq$ 40	11
9	40 < $\underline{r}$ $\leq$ 45	7
10	45 < $\underline{r}$ $\leq$ 70	7
11	70 < $\underline{r}$ $\leq$ 151	7
		<u>498</u>

Figure 1.1. Frequency histogram of recapture radii of the female Perognathus longimembris in units of trap spacing (= 22.9 m); during the summer of 1964; on the United States Atomic Energy Commission Nevada Test Site.

Frequency Distribution

Class	Class Boundaries				Class Frequency
1	0	<	r	5	29
2	5	<	r	10	72
3	10	<	r	15	64
4	15	<	r	20	62
5	20	<	r	25	41
6	25	<	r	30	34
7	30	<	r	35	14
8	35	<	r	40	11
9	40	<	r	70	10
10	70	<	r	195	8
					<u>345</u>

Figure 1.2. Frequency histogram of recapture radii of the male *Perognathus longimembris* in units of trap spacing (= 22.9 m); during the summer of 1964; on the United States Atomic Energy Commission Test Site.

$$\underline{Z} = (\underline{r}'_0 - \mu) / \sigma \quad (1.2)$$

$$\underline{r}'_0 = \mu + \underline{Z}\sigma \quad (1.3)$$

$$\underline{T}^{-1} \underline{r}' = \underline{r} \quad (1.4)$$

where $\underline{T}^{-1}$ is the inverse of the transformation $\underline{T}$, $\underline{Z}$ is the standard normal variate, and $\underline{r}'_0$ is any specified distance. Since μ and σ are unknown, these parameters can only be estimated; consequently, from equation (1.2) one can only estimate the probability that a randomly chosen $\underline{r}'$ will exceed a specified value $\underline{r}'_0$, and from equation (1.3) one can only estimate the value $\underline{r}'_0$ which exceeds a given proportion of $\underline{r}'$. Having accomplished this, one obtains equivalent statements for $\underline{r}$ by using equation (1.4).

Whereas the limit $\mu + 1.645 \sigma$ contains 95% of a normal population, the same cannot be said for the limit $\underline{r} + 1.645 \underline{s}_r$. In other words, the chance fluctuations of the sample mean and sample standard deviation affect the proportion of the distribution contained below the limit. It should be emphasized that in calculating home range area the random variable of interest is the percentage of recapture radii falling below $\underline{r} + K\underline{s}_r$. It is not possible to determine K so that the limit will always cover a specified proportion of the universe, because $\underline{r} + K\underline{s}_r$ is a random variable. Yet, by using one-sided tolerance limits, it is possible to determine the constant K so that one can assert with a degree of confidence γ that the proportion of the population below $\underline{r} + K\underline{s}_r$ is at least α (Ostle, 1963).

All of the recapture radii obtained from the trapping records were pooled to form a single universe. The transformation was ap-

plied in order to produce a transformed vector of observations on which the assumption of normality was satisfied. This made it possible to determine a one-sided tolerance interval, to which was attached a measure of assurance that the interval contains a given proportion of the population of recapture radii.

1.4. Application of the Box and Cox Transformation

The usual methods for the analysis of linear models as exemplified by the analysis of variance are usually justified by assuming that the treatment and environmental effects are additive and that the experimental errors are independent in the probability sense, have equal variance, and are distributed normally.

Box and Cox (1964) considered the problem of finding a transformation of the experimental responses $y_1, y_2, \dots, y_n$ which would produce a response metameter on which all of the important analysis of variance assumptions are satisfied. Utilizing their concept of transformations, this section presents a method for finding a transformation that produces a variable whose frequency distribution does not depart significantly from normality when operated on a series of random observations.

These ideas were applied to the pooled recapture radii of marked P. longimembris, and the vectors of observation were classified according to sex:

$$\begin{array}{l} \vec{r}_{\text{female}} = \begin{bmatrix} r_1 \\ r_2 \\ \vdots \\ r_{n_1} \end{bmatrix} \end{array} \qquad \begin{array}{l} \vec{r}_{\text{male}} = \begin{bmatrix} r_1 \\ r_2 \\ \vdots \\ r_{n_2} \end{bmatrix} \end{array}$$

where $n_1 = 480$ and $n_2 = 341$.

A chi-square test of goodness of fit was used to test whether or not this sampled population followed the normal law. The $\underline{r}$'s for the females were partitioned into 14 classes and a $\underline{X}^2$ of 97.97 was observed. Partitioning the data for the males into 12 classes resulted in a $\underline{X}^2$ of 58.28. Since the chi-square statistics indicated departure from normality, the Box and Cox transformation was applied.

This transformation is of the form:

$$\underline{r}^{(\lambda)} = \frac{\underline{r}^\lambda - 1}{\lambda} \quad (\lambda \neq 0) \quad (1.5)$$

$$= \ln \underline{r} \quad (\lambda = 0) \quad (1.6)$$

for $\underline{r}_i > 0$.

For representative values of $(\lambda_1, \lambda_2, \dots, \lambda_j)$ the transformed vector of observations $\underline{r}^{(\lambda_j)}$ was calculated, where,

$$\underline{r}^{(\lambda_j)} = \begin{bmatrix} \frac{\underline{r}_1 \lambda_j - 1}{\lambda_j} \\ \frac{\underline{r}_2 \lambda_j - 1}{\lambda_j} \\ \cdot \\ \cdot \\ \cdot \\ \frac{\underline{r}_n \lambda_j - 1}{\lambda_j} \end{bmatrix} \quad (1.7)$$

Thus the procedure involves a search on λ . Initially, the values of $\lambda = -1, 0, .5, 1$ were chosen. On the basis of the associated Fisher's g statistics the next choices of λ were indicated. The ensuing values tested were $\lambda = .45, .40, .37, .35, .33, .20$

(Fig. 1.3 and 1.4).

Fisher's g statistics, the χ^2 goodness of fit test, and the Kolmogorov-Smirnov test were all employed in order to ascertain the λ which achieves the assumption of normality for the distribution of r' . The χ^2 goodness of fit test was conducted in accordance with the recommendation of Hamdan (1963). He designated the choice of k , (the number of classes) and the width (w) of the classes. Thus k and w were constant for all λ_j , making the associated χ^2 's directly comparable. The relationship between χ^2 and λ can be seen in Fig. 1.3 and 1.4. The recommended transformation is $r'(\lambda_0)$ where λ_0 is the value which minimizes χ^2 . The results are summarized in Table 1.1.

Based on the information given in Table 1.1, the best choices of λ were .33 for the females and .35 for the males. The frequency histograms of the transformed recapture radii for the two sexes are given in Figures 1.5 and 1.6. The mean of the transformed data for the females was 4.3262 trapping units and the standard deviation was 1.440. For the males a mean of 4.6278 and a standard deviation of 1.5620.

1.5. Home Range Estimates of Perognathus longimembris

To measure home range area, a one-sided tolerance interval was specified. The tolerance limits considered depend on the assumption of normality of the sampled population. The procedure was to determine specification limits that state with a degree of confidence that the fraction of recapture radii falling below is at least γ . The specification limits were of the form $\bar{r} \pm Ks_r$. In order to determine K the following solution by Eisenhart, Hastay, and Wallis (1947) was employed.

Figure 1.3. Relationship between χ^2 and λ for the female Perognathus longimembris based on recapture data from the United States Atomic Energy Commission Nevada Test Site.

Figure 1.4. Relationship between χ^2 and λ for the male Perognathus longimembris based on recapture data from the United States Atomic Energy Commission Nevada Test Site.

Table 1.1. Tests for departure from normality of the transformed recapture radii of Perognathus longimembris

Females				
λ	Fisher's g g_1	Statistics g_2	Chi-Square (χ^2_{11})	Kolmogorov-Smirnov (D)
1.00	1.4683	3.8993	97.97	0.1021
.50	.3956	.6212	28.61	0.0417
.37	.1147	.4296	18.72	0.0271
.35	.0703	.4257	17.90	0.0271
.33	.0254	.4290	12.43	0.0175
Critical Values*	$\pm .184$	$-.33$ $+.37$	19.70	0.0620

Males				
λ	Fisher's g g_1	Statistics g_2	Chi-Square (χ^2_{11})	Kolmogorov-Smirnov (D)
1.00	1.2495	2.7770	58.28	0.0718
.50	.3433	-.1063	17.80	0.0337
.35	.0948	-.1443	10.33	0.0227
.33	.0617	-.1598	14.18	0.0227
.30	.0120	-.1748	14.36	0.0227
Critical Values*	$\pm .213$	$-.38$ $+.44$	16.90	.0740

*Values critical at the 5% level.

Frequency Distribution

Class	Class Boundaries										Class Frequency
1		-	∞	<	r'	W	r	-	2.4s		4
2		-	2.4s	<	r'	W	r	-	2.0s		8
3		-	2.0s	<	r'	W	r	-	1.6s		7
4		-	1.6s	<	r'	W	r	-	1.2s		35
5		-	1.2s	<	r'	W	r	-	.8s		43
6		-	.8s	<	r'	W	r	-	.4s		60
7		-	.4s	<	r'	W	r	-			84
8		+		<	r'	W	r	+	.4s		79
9		+	.4s	<	r'	W	r	+	.8s		62
10		+	.8s	<	r'	W	r	+	1.2s		45
11		+	1.2s	<	r'	W	r	+	1.6s		30
12		+	1.6s	<	r'	W	r	+	2.0s		12
13		+	2.0s	<	r'	W	r	+	2.4s		4
14		+	2.4s	<	r'	W	r	+	∞		7

Figure 1.5. Frequency histogram of transformed recapture radii ($\lambda = .33$) of *Perognathus longimembris*.

Frequency Distribution

Class	Class Boundaries					Class Frequency
1	-	∞	<	$\bar{r}'$	$\bar{r} - 2.0s$	4
2	$\bar{r}$	$2.0s$	<	$\bar{r}'$	$\bar{r} - 1.6s$	15
3	$\bar{r}$	$1.6s$	<	$\bar{r}'$	$\bar{r} - 1.2s$	28
4	$\bar{r}$	$1.2s$	<	$\bar{r}'$	$\bar{r} - .8s$	33
5	$\bar{r}$	$.8s$	<	$\bar{r}'$	$\bar{r} - .4s$	35
6	$\bar{r}$	$.4s$	<	$\bar{r}'$	$\bar{r}$	53
7	$\bar{r}$		<	$\bar{r}'$	$\bar{r} + .4s$	50
8	$\bar{r}$	$.4s$	<	$\bar{r}'$	$\bar{r} + .8s$	51
9	$\bar{r}$	$.8s$	<	$\bar{r}'$	$\bar{r} + 1.2s$	36
10	$\bar{r}$	$1.2s$	<	$\bar{r}'$	$\bar{r} + 1.6s$	17
11	$\bar{r}$	$1.6s$	<	$\bar{r}'$	$\bar{r} + 2.0s$	12
12	$\bar{r}$	$2.0s$	<	$\bar{r}'$	$+$ ∞	17

Figure 1.6. Frequency histogram of transformed recapture radii ($\lambda = .35$) of the male Perognathus longimembris.

Let

$$\int_{-\infty}^{\frac{K}{P}} f(\underline{z}) d\underline{z} = \alpha \quad (1.8)$$

and

$$\int_{-\infty}^K f(\underline{z}) d\underline{z} = \gamma \quad (1.9)$$

where $\underline{z}$ is the normal distribution function.

Compute

$$\underline{a} = \frac{(1 - \frac{K^2}{n} \gamma)}{2(n-1)}, \quad (1.10)$$

$$\underline{b} = \frac{\frac{K^2}{P} - \frac{K^2}{n} \gamma}{n}, \quad (1.11)$$

$$\underline{c} = \frac{\frac{K^2}{P} + \underline{c}}{\underline{a}}, \quad (1.12)$$

and

$$\underline{K} = \frac{\frac{K}{P} + \underline{c}}{\underline{a}}. \quad (1.13)$$

Table 1.2 is an abbreviated table of $\underline{K}$ factors for one-sided tolerance intervals. Values of $\underline{K}$ taken from this table give 95% confidence statements that 95% of the population will be below $\bar{r} + \underline{Ks}_r$. Much more extensive tables can be found in Owen (1957). Table 1.3 provides values of $\underline{K}$ for $\underline{n} = 480$ and $\underline{n} = 341$; $\gamma = .99$ and $.95$; and $\alpha = .995, .99, .975, .90, .85$, and $.50$.

After determining the one-sided tolerance limits for the transformed variable $\underline{r}'$, T^{-1} was applied to obtain equivalent statements

Table 1.2. One-Sided Tolerance Factors (Factors K are such that the probability is 0.95 that at least 0.95% of the distribution will lie below $\bar{r} + Ks_r$).

<u>n</u>	<u>K</u>
25	2.292
40	2.126
50	2.065
75	1.971
100	1.923
150	1.867
200	1.836
341	1.789
480	1.765
∞	1.645

Table 1.3. One-Sided Tolerance Factors (Factors K are such that the probability is γ that at least a proportion α of the distribution will lie below $\bar{r} + Ks_r$).

α	Females $\underline{n} = 480$		Males $\underline{n} = 341$	
	$\gamma(.99)$	$\gamma(.95)$	$\gamma(.99)$	$\gamma(.95)$
.995	2.813	2.740	2.861	2.772
.99	2.549	2.482	2.594	2.512
.975	2.154	2.094	2.193	2.121
.95	1.818	1.765	1.853	1.789
.90	1.434	1.387	1.464	1.408
.75	.796	.759	.820	.776
.50	.107	.075	.127	.089

for $\underline{r}$. The result of this procedure was a statement of the form "with γ confidence the reliability is at least α ", hereafter abbreviated $R(\gamma, \alpha)$.

Values of $R(\gamma, \alpha)$ are given in Table 1.4 for both sexes. Thus for the female it is predicted with 95% confidence that 99.5% of the recaptures from the grid will be less than 54.15 m from the recapture center of the captured individual. Likewise, with 95% confidence, it can be predicted that 99% of the recaptures will be less than 47.91 m from the recapture center; and 97.5% of them will be less than 41.74 m from the center. Similar estimates can be made for any other choices of γ and α .

1.6. Determination of Sample Size

It should be emphasized that home range estimates are based upon probability statements about recapture radii. The approach taken to measure home range area was to specify tolerance limits of the form $\bar{r} + Ks_r$. When considering tolerance limits, three facts are rather obvious. First, since $\underline{r}$ and $\underline{s_r}$ are random variables, the tolerance interval is a random variable. Second, the larger K the larger the tolerance interval; therefore, the higher the confidence coefficient associated with the interval, the larger it becomes for a fixed $\underline{n}$. Intuitively, this is only reasonable, since the larger the interval becomes, the more confident one can be that it contains a specified proportion. Third, the smaller K is taken, the more meaningful and useful the tolerance range becomes. The length $\bar{r} + Ks_r$ can be decreased by increasing $\underline{n}$, the number of recapture radii; however, a stage will be reached when the cost of obtaining increased accuracy becomes excessive.

1.7. Determination of Sample Time

Table 1.4. $R(\gamma, \alpha)$ (With γ - confidence the reliability is at least α).

$R(\gamma, \alpha)$	Meters	
	Females	Males
$R(.99, .995)$	55.69	59.70
$\bar{R}(.99, .99)$	49.24	52.94
$\bar{R}(.99, .975)$	42.78	46.10
$\bar{R}(.99, .95)$	36.09	38.88
$\bar{R}(.99, .90)$	31.16	33.56
$\bar{R}(.99, .75)$	22.82	24.61
$\bar{R}(.99, .50)$	15.65	16.88
$R(.95, .995)$	54.14	57.73
$\bar{R}(.95, .99)$	47.91	51.24
$\bar{R}(.95, .975)$	41.74	44.63
$\bar{R}(.95, .95)$	35.21	37.79
$\bar{R}(.95, .90)$	30.50	32.69
$\bar{R}(.95, .75)$	22.38	24.06
$\bar{R}(.95, .50)$	15.36	16.51

The cost of acquiring the trapping records suggests that desirability of determining how many recapture radii are needed to acquire a reliable estimate of home range. Furthermore, it would be useful to know how many days of trapping are needed in order to acquire a specified number of recapture radii. These notions were examined by applying them to the trapping records considered earlier. Suppose the investigator wishes to have a degree of confidence of .95 that .95 of the recapture radii of the female P. longimembris fall below $\bar{r} + 1.923 s_r$. Table 1.2 shows that the sample size must be 100.

It was found, after examining the trapping records for the females, that the average number of recaptures per day was 19.57 with a standard deviation of 11.836. The males averaged 13.07 recaptures per day with a standard deviation of 11.234. A confidence coefficient .95 was found for χ^2 , the average number of recapture radii obtained per day. The result was

$$\Pr(12.74 < \chi^2 < 26.40) = .95.$$

Since the investigator desires 100 recapture radii, a confidence interval with a confidence coefficient .95 was found for the number of days required to acquire n . An easy manipulation of the following intervals,

$$12.74 \quad \frac{\text{avg. no. of rec. radii}}{\text{day}} \quad 26.40 \quad \text{. (No. of rec. radii req.),}$$

$$\frac{1}{26.40} \quad \frac{\text{days}}{\text{avg. no. of rec. radii}} \quad \frac{1}{12.74} \quad \text{. (No. of rec. radii req.),}$$

yielded,

$$\Pr(4 < \text{days} < 8) = .95.$$

Hence, if one wishes a tolerance limit $\bar{r} + 1.923 s_r$, he should feel .95 confident that the required sample size of 100 will be acquired

after trapping between 4 and 8 days.

A similar statement for the males could be formed from the following confidence intervals:

$$\Pr(6.59 < V < 19.55) = .95$$

and

$$\Pr(5 < \text{days} < 15) = .95.$$

The trapping records of P. longimembris were used to illustrate the above concepts. It should be emphasized that the statements made about the time required to obtain 100 recapture radii apply only to P. longimembris in this specific study. The effects of variation in location, period of time, and species are variable and influence the time necessary to obtain 100 recapture radii.

1.8. Summary and Conclusions

In the statistical concept of home range each animal is assumed to have a center of activity but no fixed outer limits to his range, except such as imposed by physical or biological barriers to his movement. In general, the greater the distance from his center of activity, the lower is the probability of the occurrence.

For many species of animals it is impractical to secure the information about the movements of such animals in any way other than by retrapping of marked individuals. One acquires a set of trapping records by extending a grid of traps over an area sufficiently large to include all the activity loci of at least one individual.

A method for estimating the probability of an animal being in a particular region of the home range was presented. The ideas were applied to the records of recapture for P. longimembris on a grid of traps spaced at 22.9 m intervals at the United States Atomic Energy Commission Nevada Test Site. The Box and Cox transformations

$\underline{r}' = (\underline{r}_i^{.35} - 1)/.35$ and $\underline{r}' = (\underline{r}_i^{.33} - 1)/.33$, when applied to the female and male recapture data, respectively, produced two transformed vectors of observations on which the assumption of normality was satisfied. This justified the use of one-sided tolerance limits for a normal population. Thus it was possible to assert with a degree of confidence γ that a given percentage of the recaptures will be less than a specified distance from the recapture center of the captured animal. It is estimated with a .95 degree of confidence that of the recaptures of the females, 99% will be within 47.91 m. For the males it is estimated that 99% will be within 51.24 m of the recapture center; and 95% will be within 37.79 m. The results indicated that males have a significantly greater home range than females.

2. Home Range as a Measure of Probable Interactions Among Populations of Small Mammals

2.1. Introduction

The concept of "home range" is generally accepted as a useful population parameter, but appears to have different meanings among those who have attempted to estimate the actual area (Elton, 1932; Burt, 1943; Hayne, 1949; Mohr, 1956; Harrison, 1958; Calhoun and Casby, 1958; Mohr and Stumpf, 1964; and Jorgensen and Hayward, 1965). For species displaying distinct territorialism, the home range may be limited by defense behavior, while the limitation for other species may be the distance from burrow, nest, etc., they wander in search of food or a mate. In this latter case, the area included within their range of movement (for whatever purpose) is less easily defined, but no less important in understanding spatial distribution and interaction among members within the population. These and other behavioral characteristics, along with the many reasons investigators have had for estimating home range, have led to numerous applications and types of estimates, the interpretations of which are sometimes questionable. Several reviews have appeared in recent literature (Hayne, 1949; Dice and Clark, 1953; Harrison, 1958; Calhoun and Casby, 1958; Jackson and Strecker, 1962; and Jorgensen and Tanner, 1963); consequently no further elaboration needs to be made in this report.

Home range, in this report, is considered to be the area of a circle whose radius is determined by the distance from an estimated activity center that marked animals would most likely be recaptured within. Thus, the probability of recapture is conditional, based

upon the probability that once an animal has been captured, it will be at a particular distance from the activity center. This assumes that the relative frequency of captures at varying distances from the recapture center reflects a corresponding relative intensity of home range usage, consequently an animal would be expected to use the area closest to its activity center more intensively than areas further distant. This report does not define the type of usage an animal might put its home range to, but simply provides a method which may be used to estimate the probability that two individuals will interact in space. In this sense, interaction is implied by the probability that two animals are using overlapping portions of their home ranges concurrently.

An understanding of probable interaction in space can provide better interpretations of data concerning such factors as mating behavior, territoriality, competition, etc. Population activity, size changes, and the transmission of infectious disease agents and parasites among individuals may also be examined from the point of view of probable interaction. Important to this report is the influence population interactions may have on movement into and away from an area disturbed by nuclear detonations.

2.2 Methods

Home ranges were determined with the methods described by Dice and Clark (1953) and Jorgensen and Tanner (1963) and modified in Section 1 of this report. These methods provide a circular representation of the home range with the recapture center being the center of the circle. This procedure has been adequately described by Hayne (1949), Dice and Clark (1958), and Jorgensen and Tanner (1963). Normal distribution was used to determine the distance

from the activity center that represented a probability of recapture equal to or greater than .95. Since the probability of recapture is so remote beyond $\underline{P} = .95$, the home ranges described herein are limited to the area of the circle drawn with its radius equal to the distance prescribed by $\underline{P}$.

Only those individuals that were recaptured three or more times in at least three locations were included in these analyses. Also, if 25% or more of the recapture loci were on the periphery of the grid, the animal was excluded from the analyses.

Some individuals apparently increased their home range with infrequent extensive forays beyond what seemed normal. These forays are rare and not readily detectable when probability of usage is used to estimate home range, and unless excluded can distort the results somewhat. The recapture loci that were beyond $\underline{P} = .95$ when all recaptures were included were removed from the data and new values for $\underline{P}$ determined from those that remained. This procedure provided estimates that were probably more indicative of the actual sizes of the home ranges.

The interaction of any two individuals is a factor of the recapture radii ($\underline{a}$ and $\underline{b}$) and the distance ($\underline{c}$) between their respective recapture centers ($\underline{x}, \underline{y}$). This may be defined with $\underline{b} < \underline{a}$ and $(\underline{a} - \underline{b}) < \underline{c} < (\underline{a} + \underline{b})$, where $\underline{a}$ is the recapture radius of one animal, $\underline{b}$ is the recapture radius of the other, and $\underline{c}$ is the distance between the respective recapture centers. The term $\underline{c} = \left[(\underline{x}_b - \underline{x}_a)^2 + (\underline{y}_b - \underline{y}_a)^2 \right]^{\frac{1}{2}}$ (Fig. 2.1). Interaction would be expected when the distance between any two recapture centers is less than the sum of the radii for both. In the case of females $\underline{a}$ and $\underline{b}$ both equal 44.45 m, thus if $\underline{c} > 88.90$ interaction would

not be expected since the home ranges would not overlap.

Before the overlap area can be determined, $P_1(x_1, y_1)$ (the positive point of intersection) for the two circles representing two home ranges must be computed. It is necessary to solve the two circles simultaneously when $\underline{a}^2 = \underline{x}^2 + \underline{y}^2$ is the equation for one circle and $\underline{b}^2 = (\underline{x} - \underline{c})^2 + \underline{y}^2$ is the equation of the overlapping circle.

The solution for these two equations is:

$$\underline{x}_1 = \frac{\underline{a}^2 - \underline{b}^2 + \underline{c}^2}{2\underline{c}} \quad (2.1)$$

$$\underline{y}_1 = \sqrt{\underline{a}^2 - \frac{\underline{a}^2 - \underline{b}^2 + \underline{c}^2}{2\underline{c}}^2} \quad (2.2)$$

Since $\underline{a}$, $\underline{b}$, and $\underline{c}$ are known, $P_1(x_1, y_1)$ can be determined. In Table 2.1, it is noted that $\underline{a} = \underline{b} = 44.45$ m (since both are females) and $\underline{c}$ for L-14, R-34 equals 11.43 m. With these values, and $\underline{x}_1 = 5.72$ and $\underline{y}_1 = 44.08$, the area of overlap for L-14 and R-34 can be estimated directly by solving for $\underline{A}_1$ (see the following derivations for $\underline{A}_1$ and $\underline{A}_2$)¹. In this case $\underline{A}_1 = 5,190.91 \text{ m}^2$ and since the whole circle contains $6,207.18 \text{ m}^2$, there is an overlap area of 83.62%. Tables 2.2 and 2.3 function just like 2.1, except they include males and females, and males, respectively.

When individuals of the same species and sex are studied, the home ranges of each will be equal. In this case, the overlap area can be determined directly. When $\underline{x}_1 < \underline{c}$ the same procedure may be used. The overlap area is estimated with the use of a series of rectangles, in which case $\underline{A}_1$ is the appropriate formula to use. The arcsin is expressed in radians.

¹Derivations of these formulae were determined by Floyd Haupt of the Math Department, Brigham Young University, Provo, Utah.

Figure 2.1. An illustration of the study grid (each dot represents a station) and the overlap of home ranges for two Perognathus longimembris: a = radius of home range for one animal, b = radius of home range for another animal, c = distance between recapture centers (x, y), d = distance from recapture center to closest point of overlap, and P₁(x₁, y₁) = positive point of intersection for the two circles.

In cases where $\underline{x}_1 > \underline{c}$ the same basic procedure is used except the area outside the overlap is determined and finally subtracted from the whole. In this case $\underline{A}_2$ is the appropriate formula to use. The arcsin is expressed in radians.

When $\underline{a}$ does not equal $\underline{b}$, as is usually the case, it is necessary to solve for the area outside of the overlap and subtract from the total home range area. In this case $\underline{x}_1$ is greater than $\underline{c}$, and $\underline{A}_2$ must be solved. Examples of this procedure are found in Table 2.3 where $\underline{a} = 44.45$ m, and $\underline{b} = 41.89$ m. The distance between recapture centers ($\underline{c}$) for L-13 and L3 is 11.43 m and the values for $\underline{x}_1$ and $\underline{y}_1$ are 15.50 and 41.70, respectively. After the area of overlap has been determined ($\underline{A}_2 = 488.347 \text{ m}^2$), the percentage overlap is estimated as 78.67% of circle $\underline{a}$ and 88.58% of circle $\underline{b}$. These values are then multiplied by the probability of being captured at a distance from the recapture center equal to or greater than the distance to the border of the overlap area ($\underline{P} = .95$), to determine the probability of capture inside the overlap area, .7474 for $\underline{a}$ and .8414 for $\underline{b}$.

This may be calculated as:

$$\underline{P_o} = \frac{\underline{O}}{\underline{H}} \underline{P_d} \quad (2.7)$$

where: $\underline{P_o}$ = probability of capture within the overlap area,

$\underline{O}$ = overlap area,

$\underline{H}$ = entire home range area,

$\underline{P_d}$ = probability of capture at the distance to the border of the overlap area, it will be .95 if the recapture center is within the overlap area.

Derivations for Estimating Home Range Overlap Areas

$$\frac{A_1}{2} = \int_0^{y_1} \left[\sqrt{\underline{a}^2 - y^2} - \left(\underline{c} - \sqrt{\underline{b}^2 - y^2} \right) \right] dy \quad (2.3)$$

$$\begin{aligned} &= \int_0^{y_1} \left[\sqrt{\underline{a}^2 - y^2} - \underline{c} + \sqrt{\underline{b}^2 - y^2} \right] dy \\ &= \left[\frac{y}{2} \sqrt{\underline{a}^2 - y^2} + \frac{\underline{a}^2}{2} \arcsin \frac{y}{\underline{a}} - \underline{c}y + \frac{y}{2} \sqrt{\underline{b}^2 - y^2} + \frac{\underline{b}^2}{2} \arcsin \frac{y}{\underline{b}} \right]_0^{y_1} \\ \frac{A_1}{2} &= 2 \left[\frac{y_1}{2} \sqrt{\underline{a}^2 - y_1^2} + \frac{\underline{a}^2}{2} \arcsin \frac{y_1}{\underline{a}} - \underline{c}y_1 + \frac{y_1}{2} \sqrt{\underline{b}^2 - y_1^2} + \frac{\underline{b}^2}{2} \arcsin \frac{y_1}{\underline{b}} \right] \end{aligned} \quad (2.4)$$

$$\frac{A_2}{2} = \int_0^y \left[\left(\underline{c} + \sqrt{\underline{b}^2 - y^2} \right) - \sqrt{\underline{a}^2 - y^2} \right] dy \quad (2.5)$$

$$\begin{aligned} &= \int_0^y \left[\underline{c} + \sqrt{\underline{b}^2 - y^2} - \sqrt{\underline{a}^2 - y^2} \right] dy \\ &= \left[-\frac{y}{2} \sqrt{\underline{a}^2 - y^2} - \frac{\underline{a}^2}{2} \arcsin \frac{y}{\underline{a}} + \underline{c}y + \frac{y}{2} \sqrt{\underline{b}^2 - y^2} + \frac{\underline{b}^2}{2} \arcsin \frac{y}{\underline{b}} \right]_0^{y_1} \\ \frac{A_2}{2} &= \pi \underline{b}^2 - 2 \left[-\frac{y_1}{2} \sqrt{\underline{a}^2 - y_1^2} - \frac{\underline{a}^2}{2} \arcsin \frac{y_1}{\underline{a}} + \underline{c}y_1 + \frac{y_1}{2} \sqrt{\underline{b}^2 - y_1^2} + \frac{\underline{b}^2}{2} \arcsin \frac{y_1}{\underline{b}} \right] \end{aligned} \quad (2.6)$$

Table 2.1. Summary of the analysis for probable interaction between ten pairs of Perognathus longimembris females.

Specimens analysed	Dist.betw. recapture centers ^a (<u>c</u>)	Percent of area overlapped (<u>O/H</u>)	Prob. of capture at distance <u>d</u> (<u>P_d</u>)	Prob. of capture inside overlap area (<u>P_o</u>)	Prob. of interaction (<u>P_i</u>)
L-14, R-34	11.43	83.62	.9500	.7938	.6301
L-3, R34-3	16.16	76.98	.9500	.7313	.5348
L23, R-24	25.56	63.89	.9500	.6070	.3684
L4-12, R23	37.90	47.38	.9500	.4501	.2026
L34-13, R1-3	47.10	35.83	.8933	.3201	.1025
L3-13, R34-3	55.98	25.48	.7036	.1793	.0321
L14-4, L14-12	68.58	12.65	.4571	.0578	.0033
L34-4, L14-12	76.68	5.97	.2612	.0156	.0002
L-4, L34-13 ^b	84.76	1.19	.0884	.0011	.0000
L-12, R34-3 ^b	88.53	.03	.0083	.0000	.0000

^aMeasurements are expressed as meters; recapture radii, a = b = 44.45. Percentage of area overlapped (O/H), P_d, and P_o are equal when a = b.

^bThough there is a slight overlap in home ranges, the probability of interaction (P_i) is so low that it is essentially zero.

Table 2.2. Summary of the analysis for probable interaction between eleven pairs of Perognathus longimembris males.

Specimens Analysed	Dist.betw. recapture centers $\underline{a}$ ($\underline{c}$)	Percent of area overlapped ($\underline{O}/\underline{H}$)	Prob.of capture at distance $\underline{d}$ ($\underline{P}_d$)	Prob. of capture inside over lap area ($\underline{P}_o$)	Prob. of interac- tion ($\underline{P}_i$)
L3-23, L2-34	3.89	94.14	.9500	.8943	.7997
L2-14, L23-12	6.74	89.71	.9500	.8522	.7262
L12, L13-4	17.72	73.19	.9500	.6953	.4834
L-24, L13-1	29.15	56.54	.9500	.5371	.2884
L1-23, L2-3	35.20	48.95	.9500	.4650	.2162
R12-13, L34-1	45.38	34.55	.8667	.2994	.0896
L2-2, R1-1	52.59	26.33	.6946	.1828	.0334
L3-1, L12-14	67.63	09.85	.3356	.0330	.0010
L13-1, R1-1 ^b	77.54	02.37	.0990	.0023	.0000
L-24, L3-1 ^b	80.03	01.10	.0396	.0004	.0000
L34-2, L23-12 ^b	82.44	00.19	.0000	.0000	.0000

^aMeasurements are expressed as meters; recapture radii, $\underline{a} = \underline{b} = 41.89$.
Percentage of area overlapped ($\underline{O}/\underline{H}$, $\underline{P}_d$, and $\underline{P}_o$ are equal when $\underline{a} = \underline{b}$.

^bThough there is a slight overlap in home ranges, the probability of interaction ($\underline{P}_i$) is so low that it is essentially zero.

Table 2.3 Summary of the analysis for probable interaction between ten Perognathus longimembris males and females.

Specimens analysed	Dist. betw. recapture centers ^a	Percent of area overlapped (O/H)		Prob. of capture at dist. $d(P_d)$		Prob. of capture inside overlap area (P_o)		Prob. of interaction (P_i)
		<u>a</u>	<u>b</u>	<u>a</u>	<u>b</u>	<u>a</u>	<u>b</u>	
L-13, L3	11.43	78.67	88.57	.9500	.9500	.7474	.8414	.6289
L2-3, L14-24	16.16	73.83	83.14	.9500	.9500	.7014	.7898	.5540
R24, L34-13	25.56	64.93	73.11	.9500	.9500	.6168	.6945	.4284
R24, L4-34	37.90	48.96	54.96	.9500	.9500	.4637	.5221	.2421
L4-2, L14-24	47.13	35.92	40.45	.8381	.8893	.3010	.3597	.1083
L24-3, L34-13	55.98	28.72	32.32	.5895	.6886	.1693	.2226	.0377
R4-2, L4-12	68.58	16.78	18.90	.3796	.4928	.0637	.0931	.0059
L14-2, L-34	76.68	11.46	12.90	.2064	.2192	.0237	.0283	.0007
R-1, R23 ^b	84.76	9.56	10.76	.0338	.0359	.0029	.0039	.0000
R34-1, L4-12 ^b	85.53	6.34	7.14	.0174	.0184	.0011	.0013	.0000

^aMeasurements are expressed as meters; recapture radii, a = 44.45 (female), b = 41.89 (males).

^bThough there is a slight overlap in home ranges, the probability of interaction (P_i) is so low that it is essentially zero.

The probability of interaction ($P_{\underline{i}}$) is finally determined by multiplying the two $P_{\underline{o}}$ values for the animals concerned. Examples of all these situations are presented in Tables 2.1, 2.2, and 2.3.

Distances between the recapture centers and the nearest point on the borders of overlap must be determined before one can estimate the probability of recapture within the overlap area. When $\underline{a} = \underline{b}$ and $\underline{c}$ is greater than $\underline{a}$, $\underline{d} = \underline{c} - \underline{a}$, where $\underline{d}$ is the distance from the recapture center to the nearest point on the overlap border. In this case, the probability of being within the overlap area is determined for the distance beyond $\underline{d}$ which is the overlap area. If recapture centers are within the overlap area, the probability that an animal will be within the designated overlap area ($P_{\underline{o}}$) is always .95. This situation exists when $\underline{a} = \underline{b}$ and $\underline{c}$ is less than $\underline{a}$.

If $\underline{a}$ does not equal $\underline{b}$ and $\underline{a}$ is greater than $\underline{b}$, one of the following three procedures is required to determine the probability of recapture inside the overlap area. (1) When $\underline{c}$ is less than or equal to $\underline{b}$, $P_{\underline{o}} = .95$ since both recapture centers are located inside this area. (2) if $\underline{a}$ is less than $\underline{c}$, $\underline{d}_{\underline{a}} = \underline{c} - \underline{b}$ and $\underline{d}_{\underline{b}} = \underline{c} - \underline{a}$. (3) When $\underline{a}$ is greater than or equal to $\underline{c}$ and $\underline{c}$ is greater than $\underline{b}$, $\underline{d}_{\underline{a}}$ is determined as $\underline{c} - \underline{d}$. The probability of recapturing $\underline{b}$ inside the overlap area is .95 since its center is within this area (Fig. 2.1). Snedecor (1946, Table 8.6) was used throughout these studies to determine the probabilities of recapture inside the overlap areas.

If followed, this technique should allow one to estimate the relative probability of interaction in space for any set of two individuals. Several assumptions have been made that are rather outstanding and should always be kept in mind. One is that interaction is possible whenever the animals are active at the same time, whereas actually it

is possible only when they both move in the direction of the area of overlap at the same time. For this reason, it is possible that the estimates resulting from this procedure may be somewhat high, but this seems not to distract too much from its usefulness in determining relative probable interactions.

Another factor which is not considered in this procedure is the second, third, etc. order interactions involving more than just two animals using the same space. It is also assumed that interaction is evident whenever two animals are within the overlap area, regardless of what they are doing or how close they are to each other. Likewise, the whole overlap area is assumed to have the same probability of interaction. These problems are subjects of other analyses which are presently under consideration, but not yet resolved.

2.3 Application to Data

The field descriptions and methods used to gather data for this study are presented in Section 1.2. After 10 days of continuous operation, one trap was removed from each station since no more than two animals were trapped at one station in one night.

Approximately 255 individual P. longimembris were marked inside the grid during the 30-day trapping period, but only 26 males and 41 females were used in the analyses. The remaining 188 were not used because of numerous reasons, but the largest portion were simply recaptured too infrequently.

Since this study is concerned primarily with interactions between individuals, it will not be necessary to determine all possible interactions to demonstrate the procedure. Enough will be determined to illustrate all of the possibilities discussed in the methods. The application of this method will be discussed further in Section 3.

Males and females will be used to illustrate the technique for individuals whose radii are equal. In these cases, the recapture radii (a and b) are equal to 41.89 and 44.45 m, respectively, and the average number of recaptures, 26 males is 7.0 (ranging from 3-14), and for 41 females it is 6.9 (ranging from 3 to 18). The computation and results of the exemplary interactions are presented in Tables 2.1 and 2.2. These could conveniently be extended to include all possible interactions between individuals.

Females vs. males were used to illustrate the application of this technique to individuals whose recapture radii are not equal. In this case the recapture radii for the females (a) was 44.45 m, and 41.89 m for the males (b). The computation and results of the exemplary interactions are presented in Table 2.3 and likewise, could be extended to include all possible interactions between individuals.

2.5 Discussion

Data leading to an understanding of individual and population behavior are essential for conclusive evaluation of environmental effects, regardless of what environmental factors are under consideration. This is particularly apropos when one is attempting to evaluate the reactions of populations to induced changes in the environment, eg. an underground nuclear detonation. One of the most basic population behavior reactions is the "home range", which is generally interpreted by workers as a type of measure of interaction among the members of the population. This statistic may vary with changes in the environment, and thus may possibly be useful in interpreting certain environmental stresses such as food reduction, mating competition, population growth, etc. But, only in cases where the home range proves useful in measuring interaction within the population is its study particularly useful,

for only then can one attempt to determine the effects of the environment on the population.

This paper has presented one possible technique that might be used to measure interaction with a computed home range value. Though useful analytically, this technique requires several assumptions that must be clearly understood along with their respective limitations. The first of these is the prescribed round home range, which is not entirely realistic. A round home range is used as a means of quantifying the area and identifying a center of activity, and is not intended to prescribe real home range boundaries. Though somewhat unrealistic, this estimate seems not to introduce a serious mathematical error and has the added advantage of allowing a means of estimating probable interactions.

Another assumption is simultaneous activity of all animals in the population. This assumption has usually been accepted or ignored by most workers, but has not clearly demonstrated and should be examined further since it is also important in understanding several other population characteristics. The present study assumes simultaneous activity and differential use of the home range area. It is possible that the reverse (simultaneous occupation of the entire home range and differential use of the time) could also be assumed. In this case, the overlap area becomes an estimate of time and would be multiplied by the P_i to obtain an even more refined estimate of probability of interaction. Obviously, the values would be much smaller, but time awaits more definitive data before its significance can be appraised.

The third assumption is that if two animals are within the area of overlap, they are bound to interact, regardless of the size of overlap. This assumption holds many difficulties and will have to be evaluated

more precisely as data becomes available. It is more likely that interactions occur only after individuals are within a given distance on one another. The last two assumptions have the tendency to reduce the probability of interaction, and when resolved, the resulting values will doubtlessly be smaller.

There are also some cautions of interpretation that should be mentioned. If the data were collected over an extended period of time, the recapture centers could possibly adjust somewhat and this would result in rather significant increases in recapture radii. For this reason, data must be gathered in as short a period as possible, preferably during periods of activity that are common to certain members of the population, such as mating, lactating, etc. To estimate probable interaction for any given species, several sets of data are necessary, and these gathered throughout the year.

The advantage of this method is primarily that of a convenient computer technique that can be adopted for almost any population. Probable interactions in space can be measured, and demonstrated mathematically to be much smaller than would be expected if only the size of the home range is considered. When time and the distance required for interaction are imposed on this technique, the probabilities will be reduced even more. This allows for a reasonable explanation of the large numbers of individuals co-inhabitating a single area. It also allows for what might be a more realistic approach to interpreting territorialism among small mammals. All factors considered, this method of estimating probability of interaction among small mammals seems to have advantages of convenience and realistic interpretation of home range data that are sufficient to allow an adjustment for the limitations.

3. Spatial Relationships of a Population of *Perognathus longimembris*

3.1. Introduction

Populations of small mammals are continuously adjusting to changes in their numbers and environment. As members are added or removed from the environment, the animals already present are forced to adjust; thus, placing the population in a constant state of change. This results in a continuous disruption of the social organization (Calhoun; 1962, 1963). This organization may be examined from the viewpoint of social tolerances among the members of the population. It is plausible that certain organisms are more likely to be tolerated in the population than others, and likewise, that the removal of certain individuals will force a greater adjustment than if others were removed.

This social structure must be at least partially understood before its adjustment to an underground nuclear detonation can be evaluated. The purpose of this study is to determine the social structure of a population of *P. longimembris* in space, and attempt to estimate the tolerance levels for the classes of individuals, i.e., adult and sub-adult males, and adult and sub-adult females.

3.2. Methods

Essentially, the methods used to determine the spatial relationships are the utilization of the techniques described in Section 2. The data from Tables 2.1, 2.2, and 2.3 were plotted to form curves that were used to estimate P_{ij} for the rest of the possible interactions in the population. Curves were developed rather than computing P_{ij} for each interaction, since it was much less time consuming and considered to be reasonably accurate.

Two approaches were used to arrive at a mean value for all possible $\underline{P_i}$'s. The first was to include the probable interaction of nearest neighbors, the second was to include all individuals included with the periphery of the grid. Those with recapture centers on the periphery of the grid were not included in the latter analysis. After the respective $\underline{P_i}$'s had been determined, the means were subjected to a t - test to determine if the difference between means was significant ($p = .90$).

3.3. Results

The data from Tables 2.1, 2.2, and 2.3 are presented in graphic form in Figs. 3.1, 3.2, and 3.3. The remainder of the $\underline{P_i}$'s were estimated from these three curves. After the $\underline{P_i}$'s for all combinations had been determined, contrasts were made to estimate the tolerances different classes within the population had for their own class as well as other classes (Table 3.1). This table includes average $\underline{P_i}$ estimates for nearest neighbors only.

When the values in Table 3.1 are ranked in a descending order, it is evident that adults of the same sex are the least tolerant of one another while the adults of opposite sexes are the most tolerant ($\underline{P_i} = .5507$). Adult males show relatively little tolerance for subadult males when contrasted with the adult females tolerance for subadult females. Means for these respective classes were tested to determine if there was a significant difference between them. The results of this analysis is summarized in Table 3.2.

The results of these tests may be extended further for other t values to estimate the relative tolerances different classes have for one another. These results are found in Table 3.3.

Figure 3.1. Probability of interaction between female Perognathus longimembris.

Figure 3.2. Probability of interaction between male Perognathus longimembris.

Figure 3.3. Probability of interaction between males and females of Perognathus longimembris.

Table 3.1. Contrasts of probability of interaction between nearest neighbors of different classes within a population of Perognathus longimembris at the U. S. Atomic Energy Commission Nevada Test Site.

Class Contrasts				Avg. Probability of Interaction (P_i)
A	Male adults	vs	Male subadults	.4531
B	Male adults	vs	Male adults	.4053
C	Male adults	vs	Female adults	.5507
D	Female adults	vs	Female adults	.4283
E	Female adults	vs	Female subadults	.4896

Table 3.2. Contrasts of means between nearest neighbors of different classes within a population of Perognathus longimembris at the U. S. Atomic Energy Commission Nevada Test Site.

Contrasts of Mean Values for the Probability of Interaction ^a			Degrees of Freedom	<u>t</u>
A	vs	B	80	1.007
A	vs	C	80	-2.3689 ^b
A	vs	D	99	.5916
A	vs	E	99	- .8407
B	vs	C	80	-3.7883 ^b
B	vs	D	99	- .5874
B	vs	E	99	-2.0672 ^b
C	vs	D	99	3.9162 ^b
C	vs	E	99	1.8365 ^b
D	vs	E	118	1.7947 ^b

^a A through E refer to the designation in Table 3.1.

^b There is a significant different between means at $p = .90$.

Table 3.3. Relative social tolerance demonstrated by different classes within a population of Perognathus longimembris at the U. S. Atomic Energy Commission Nevada Test Site.

Contrasts of means values for the Probability of Interaction ^a			Level of Significant Differences				
			.90	.95	.975	.995	.9995
A	vs	B ^b					
A	vs	C			X		
A	vs	D ^b					
A	vs	E ^b					
B	vs	C					X
B	vs	D ^b					
B	vs	E			X		
C	vs	D					X
C	vs	E				X	
D	vs	E		X			

^a A through E refer to the designations in Table 3.1.

^b Not significant at $p = .90$.

3.4. Discussion and Conclusions

One must consider some of the factors which stimulate animal movement before an understanding of animal invasion can be obtained. Generally, an acceptable habitat must be available and include such things as burrowing sites, food, cover, etc.; but invasion is still unlikely unless the population is in a condition where its members are searching for new or additional territory. If this condition occurs, one would expect movement within the population, with an invasion of new, unoccupied areas becoming a natural possibility.

This study was conducted essentially to determine what portion of the population might be expected to participate in the invasion, due to internal population pressures. The index for this assessment was the apparent tolerance organisms have for one another. The following conclusions were formed in order of descending tolerance levels:

adult males	and	adult females,
adult females	and	subadult females,
adult males	and	subadult males,
adult females	and	adult females,
adult males	and	adult males.

When the differences between means for these tolerance indexes were compared, it was generally concluded that adults of opposite sexes were significantly more tolerant of one another than any other class contrast. Adults were least tolerant of adults of their own sexes. Females were significantly less tolerant of the female subadults than the adult males were of the male subadults.

Though these data may indicate where the pressure might be coming from, it does not allow one to predict which class is likely to do most of the moving or invasion. These results, when coupled with the two subsequent invasion studies should form the basis of an understanding of invasion into the area disturbed by Sedan.

4. Small Mammal Invasion of a Trapped-out Habitat

4.1. Introduction

Small mammals, with their numerous adaptations, have successfully inhabited most biotic communities. Interactions arising from competition among small mammals in these communities may lead to a rather complex social organization with poorly defined boundaries which limit the movement of individuals. Important among these are territorial boundaries sometimes established by small mammals to protect all or part of their home range.

Studies of small mammal populations are generally rather recent, most occurring within the past 25 years, and work dealing specifically with small mammal invasion is limited. Observations of Peromyscus invasion of a partially trapped-out 1.8 ha habitat, in a blue-grass association in Michigan, were made by Blair (1940). Spencer (1941) studied the invasion of Citellus, Dipodomys, Neotoma, Perognathus, and Peromyscus into a 2.0 ha void in the upper sonoran desert. In another early study Stickle (1946) live trapped, marked, and released a population of Peromyscus in a 6.88 ha area of deciduous forest. A central .40 ha void was then established and subsequent invasion was observed. In forested regions of Maryland and New York, Calhoun and Webb (1953) established study areas to examine the effect of a population void on invasion by Blarina, Clethrionomys, Peromyscus, and Sorex. More recent studies include work by Andrzejewski and Wroclawek (1962) who trapped-out Apodemus and Clethrionomys from several experimental areas in Poland to observe subsequent invasion. A similar invasion study was also made by Andrzejewski (1963). The invasion of trapped-out

island and mainland habitats (northern hardwood) by Clethrionomys, Microtis, Peromyscus and Sorex was recently studied by Webb (1965).

The invasion of a trapped-out habitat by small mammals may be examined in several different ways including rate of invasion, home site origin, relationship of invasion rate to population density, age of invaders, sex of invaders, etc. Rates of invasion, home site origin, and the relationship of invasion to population density have received more attention than the latter two.

The purpose of this study is to examine the small mammal invasion of a trapped-out habitat where inhibiting boundaries caused by small mammal occupation are no longer present. Emphasis is placed on examination of the possible relationship between animal age and invasion tendency for Perognathus longimembris (age-invasion correlation). Observations are also made on a possible sex-invasion correlation. Observations are made on rates of invasion, home site origin, and the relationship of invasion to population density for all species.

4.2. Description of the Study Area

The study was conducted at the Nevada Test Site, which is about 70 miles northwest of Las Vegas, Nevada, and covers an area of approximately 1300 sq. miles. The study area was relatively undisturbed in a Grayia-Lycium community (Allred, Beck, and Jorgensen, 1963) in the northeast part of Yucca Flat (Table 4.1).

4.3. Field Methods

A 6.31 ha grid was established with 12 parallel transects (A-L) established at 22.9 m intervals. Each transect consisted of 12 trapping stations at 22.9 m intervals and numbered from 1-12. Two Young type live traps were placed at each of the 144 trapping stations. Four plant analysis transects running parallel with the grid borders

Table 4.1. Vegetation analysis of the small mammal study grid.

Plant Species	Percent Composition				
	Main Grid	Border Areas ^a			
		M	N	O	P
<u>Atriplex canescens</u>	.00	1.54	.00	.00	.00
<u>Chrysothamnus viscidiflorus</u>	7.26	.00	5.91	2.26	4.25
<u>Coleogyne ramosissima</u>	9.30	8.60	.00	13.13	74.52
<u>Ephedra nevadensis</u>	5.35	2.69	.00	3.85	1.95
<u>Eurotia lanata</u>	.89	.00	3.64	.77	.00
<u>Grayia spinosa</u>	55.55	63.80	43.78	56.21	12.21
<u>Lycium andersonii</u>	11.91	7.14	2.91	12.92	4.87
<u>Oryzopsis hymenoides</u>	1.20	2.84	6.73	.00	.31
<u>Sitanion hansenii</u>	1.79	1.06	.00	.00	.00
<u>Stipa speciosa</u>	5.78	4.87	37.03	9.95	.00
<u>Tetradymia glabrata</u>	.00	1.79	.00	.00	1.86
<u>Yucca brevifolia</u>	.31	.00	.00	.00	.00
Percent Plant Cover	13.50	12.32	10.99	19.50	22.61

^aBorder areas include plant analyses taken on four transects (M-south, N-west, O-north, and P-east) running parallel to and 31.4 m outside of the grid borders.

were established 91.4 m from the grid and designated as M (south) N (west) O (north), and P (east).

Small mammals were trapped and removed on a daily basis from June 7 through Sept. 5, 1964, and from June 9 through Sept. 7, 1965. Traps were baited and animals removed prior to 9:00 AM each day. Traps were baited with small amounts of rolled oats to avoid unnecessary attraction of jack rabbits (Lepus californicus deserticola (Mearns)) which frequently rob traps of their bait (Jorgensen, 1962). Small mammals were removed from traps, killed, and taken to the laboratory where station of capture, date, species, apparent stage of development, and sex were recorded.

Before trapping began in 1965, six 251.5 m transects were established parallel to the west border at 91.4 intervals. These transects were designated in order from the grid out as Q through V. Twelve Young type live traps were placed at 22.9 m intervals along each transect. Small mammals were trapped, toe marked, and released on these transects at two week intervals throughout the summer of 1965. Concurrently, all captures in the grid were checked for marks to determine possible home site origin of the invaders from outside.

During Aug. 1965 three transects approximately 457.2 m long were established three miles southwest of the grid and designated as W. Fifty snap traps were placed on each transect and operated for seven intermittent nights between Aug. 15 and Sept. 7, 1965. All P. longimembris caught were taken to the laboratory for age analyses and comparison with those invading the grid.

4.4. Analysis Methods

Aging methods for most small mammals are not available. Howard Kaaz (University of California, Los Angeles, California, unpublished

data) had developed a tooth wear technique to age Perognathus. This method (in the form of a key) was used to determine the age of P. longimembris invading the grid. Since age determining techniques are not available for the other species collected in this study, no effort was made to determine their respective ages.

Key to the Ages of Perognathus longimembris¹

1. Deciduous milk tooth present.....0-3 months.
Deciduous milk tooth replaced by pre-molar 4 (PM₄).....2
2. No wear evident on PM₄, molar 1 (M₁), and molar 2 (M₂) as shown
by lack of dentine lakes.....3-4.5 months.
Wear evident (dentine lakes formed) on PM₄, M₁, and M₂.....3
3. Protostyle and entostyle separate with enamel crest bisected
completely in M₁ and M₂.....4.5-6 months.
Protostyle and entostyle² or M₁ and/or M₂ not separate; enamel
crests of M₁ and/or M₂ no longer bisected completely.....4
4. Protostyle and entostyle of M₂ joined internally forming a single
dentine lake; those of M₁ not joined.....6-9 months.
Protostyle and entostyle joined forming single dentine lakes in
M₁ and M₂.....5
5. Protostyle and entostyle of M₁ narrowly joined forming a single
dentine lake; Protoloph and metaloph of PM₄ not joined..9-12 mos.
Protostyle and entostyle of M₁ more broadly joined and protoloph
and metaloph of PM₄ fused.....6
6. Posterior margin of protoloph and anterior margin of metaloph of
PM₄ fused but dentine lakes still broadly separate...12-16 months.
Anterior and posterior lakes of PM₄ nearly joined or joined.....7
7. Anterior and posterior dentine lakes of PM₄ nearly joined..16-20 mos.
Anterior and posterior dentine lakes of PM₄ joined.....8
8. Anterior and posterior dentine lakes of PM₄ narrowly joined.20-24 mos.
Anterior and posterior dentine lakes of PM₄ more broadly joined..9
9. PM₄ with one well defined clover leaf shaped dentine lake and with
lateral reintrant folds still persistent; M₁ and M₂ with buccal
reintrant folds shallow and worn smooth.....24-28 months.
PM₄ with more rounded dentine lakes and lateral reintrant folds ob-
literated or nearly so; M₁ and M₂ with buccal reintrant folds
vestigial or nearly so.....10

¹The responsibility for adapting this technique to P. longimembris lies entirely with the author.

10. PM₄ with one broad triangular dentine lake and with lateral rein-
 trant folds present but nearly obliterated; M₁ and M₂ with buccal
 reintrant folds nearly vestigial.....28-35 months.
 PM₄ with lateral reintrant folds vestigial; M₁ and M₂ with buccal
 reintrant folds vestigial.....35-42 months.

4.5. Results

Small mammals trapped in the grid include: Ammospermophilus leucurus leucurus (Merriam), Dipodomys microps occidentalis Hall and Dale, Dipodomys merriami merriami Mearns, Neotoma lepida lepida Thomas, Onychomys torridus longicaudus Merriam, Perognathus formosus mohavensis Huey, Perognathus longimembris, Perognathus parvus olivaceus Merriam, Peromyscus crinitus stephensi Mearns, and Peromyscus maniculatus sonoriensis (LeConte) (Jorgensen and Hayward, 1965). Only P. longimembris, D. merriami, D. microps, and O. torridus invaded the grid in sufficient numbers to allow further analyses.

In studying the rate of invasion or any characteristic of invasion into a trapped-out habitat the point at which newly trapped animals represent invaders must be determined. In this study the number of animals trapped daily leveled off at the sixth day after trapping in 1964 and those trapped after that were considered to be invaders. In support of this observation it was found that after the fifth day of trapping almost all the captures were within 68.6 m of the grid borders. These data agree with similar data gathered by Jorgensen (Brigham Young University, Provo, Utah, unpublished data) in another grid at the test site.

The first five trap nights in 1964 included the period from June 7 through June 11. In this five day trapping-out period 181 small mammals were removed (127 P. longimembris, 17 D. microps, 17 A. leucurus, 11 O. torridus, 6 D. merriami, and 3 P. maniculatus). The 12th of June

(sixth trapping day) is omitted from the above estimates and the invasion analyses since it was considered a buffer period between the trapping-out of the original population and the invasion of new individuals. For purposes of analyses, invasion data from June 13, 1964 to Aug. 25, 1964 was divided into three periods; June 13-30, July 1-31, and Aug. 1-25.

In 1965 small mammals that had invaded and settled since the preceding summer were removed on the same basis as the removal of the original population. The trapping-out period was from June 9 to June 13 with June 14 allowed as the buffer day. Those small mammals removed included 38 P. longimembris, 5 D. merriami, 5 O. torridus, 5 A. leucurus, 4 D. microps, and 2 P. formosus. Invasion data for the 1965 season was divided into periods from June 15-30, July 1-31, and Aug. 15-Sept. 7.

The results of age analyses for P. longimembris are presented in Tables 4.2, 4.3, 4.4, and 4.5. In these tables P. longimembris is divided into age classes for which mean ages ($\bar{x}$) are given. Thus a juvenile (0-3 months) is given an $\bar{x}$ age of 1.5 months. The formula used to determine the mean age of each population ($\bar{X} = \sum (fx)/n$) is self explanatory.

Further analyses of these means were necessary to determine if a significant difference exists between the mean ages of the sample periods. The t-test was used to test the difference between trapping period means in 1964 (Table 4.2), assuming the data do not deviate significantly from normal (Ostle, 1963). The confidence interval for this test is determined by the sample size (n) (Mendenhall, 1963). These analyses indicated that $\bar{X}_1 = \bar{X}_2$ ($p \leq .05$) and $\bar{X}_3 = \bar{X}_4$ ($p \leq .10$). All other tests for 1964 indicated a significant difference in the means

Table 4.2. Mean ages of Perognathus longimembris trapped in the grid during the 1964 trapping periods.

Trapping Intervals	Age Class	$\bar{X}$ Age for Class (months)	Frequency (f)	$f\bar{x}$
June 7-11 ^a	Juvenile	1.50	0	0.00
	Juv + PM ₄ ^b	3.75	0	0.00
	1	5.25	7	36.75
	2	7.50	11	86.25
	3	10.50	5	52.50
	4	14.00	8	112.00
	5	18.00	16	288.00
	6	22.00	21	462.00
	7	26.00	25	650.00
	8	31.50	29	913.00
	9	38.50	6	231.00
			$\underline{n} = 128$	$\bar{X}_1 = 22.13$
June 13-30	Juvenile	1.50	1	1.50
	Juv + PM ₄ ^b	3.75	0	0.00
	1	5.25	7	36.75
	2	7.50	6	45.00
	3	10.50	5	52.50
	4	14.00	2	28.00
	5	18.00	4	72.00
	6	22.00	10	220.00
	7	26.00	11	286.00
	8	31.50	12	378.00
	9	38.50	5	192.50
			$\underline{n} = 63$	$\bar{X}_2 = 20.83$

Table 4.2. (continued)

Trapping Intervals	Age Class	$\bar{X}$ Age for Class (months)	Frequency (f)	$f\bar{x}$
July 1-31	Juvenile	1.50	1	1.59
	Juv + PM ₄ ^b	3.75	6	22.50
	1	5.25	1	5.25
	2	7.50	2	15.00
	3	10.50	2	21.00
	4	14.00	1	14.00
	5	18.00	3	54.00
	6	22.00	2	44.00
	7	26.00	4	104.00
	8	31.50	4	126.00
	9	38.00	1	38.50
			$\underline{n} = 27$	$\bar{X}_3 = 16.00$
Aug. 1-25	Juvenile	1.50	1	1.50
	Juv + PM ₄ ^b	3.75	9	33.75
	1	5.25	1	5.25
	2	7.50	2	15.00
	3	10.50	1	10.50
	4	14.00	1	14.00
	5	18.00	0	0.00
	6	22.00	6	132.00
	7	26.00	2	52.00
	8	31.50	3	94.50
	9	38.50	1	38.59
			$\underline{n} = 27$	$\bar{X}_4 = 14.70$

^aTrapping-out period.^bRefer to the Key to the ages (Couplet 1) for explanation (Section 4.4).

Table 4.3. Mean ages of Perognathus longimembris trapped in the grid during the 1965 trapping periods.

Trapping Intervals	Age Class	$\bar{X}$ Age for Class (months)	Frequency (f)	$\bar{fx}$
June 9-13 ^a	Juvenile	1.50	0	0.00
	Juv. + PM ₄ ^b	3.75	0	3.75
	1	5.25	2	10.50
	2	7.50	3	22.50
	3	10.50	6	63.00
	4	14.00	2	28.00
	5	18.00	1	18.00
	6	22.00	4	88.00
	7	26.00	9	234.00
	8	31.50	7	220.00
	9	38.50	3	115.50
			$\underline{n} = 37$	$\bar{X}_1 = 21.62$
June 15-30	Juvenile	1.50	0	0.00
	Juv. + PM ₄ ^b	3.75	0	0.00
	1	5.25	0	0.00
	2	7.50	0	0.00
	3	10.50	1	10.50
	4	15.00	0	0.00
	5	18.00	0	0.00
	6	22.00	1	22.00
	7	26.00	1	26.00
	8	31.50	1	31.50
	9	38.50	0	0.00
			$\underline{n} = 4$	$\bar{X}_2 = 18.00$

Table 4.3. (continued).

Trapping Intervals	Age Class	$\bar{X}$ Age for Class (months)	Frequency (f)	$f\bar{x}$
July 1-31	Juvenile	1.50	13	19.50
	Juv + PM ₄ ^b	3.75	18	67.50
	1	5.25	0	0.00
	2	7.50	0	0.00
	3	10.50	0	0.00
	4	14.00	0	0.00
	5	18.00	0	0.00
	6	22.00	0	0.00
	7	26.00	1	26.00
	8	31.50	1	31.50
	9	38.50	0	0.00
			$n = 33$	$\bar{X}_3 = 4.38$
Aug. 15- Sept. 7	Juvenile	1.50	242	363.00
	Juv + PM ₄ ^b	3.75	302	1162.50
	1	5.25	32	168.00
	2	7.50	2	15.00
	3	10.50	0	0.00
	4	14.00	0	0.00
	5	18.00	0	0.00
	6	22.00	2	44.00
	7	26.00	3	78.00
	8	31.50	4	126.00
	9	49.50	0	0.00
			$n = 587$	$\bar{X}_4 = 3.28$

^aTrapping-out period.^bRefer to the Key to the ages (Couplet 1) for explanation (Section 4.4).

Table 4.4. Mean ages of invading Perognathus longimembris trapped in the grid during 1964 and 1965.

Trapping Intervals	Age Class	$\bar{X}$ Age for Class (months)	Frequency (f)	$f\bar{x}$
June 13-Aug. 25, 1964	Juvenile	1.50	3	4.50
	Juv + PM ₄ ^a	3.75	15	56.25
	1	5.25	9	47.25
	2	7.50	10	75.00
	3	10.50	8	84.00
	4	15.00	4	56.00
	5	18.00	7	126.00
	6	22.00	18	396.00
	7	26.00	17	442.00
	8	31.50	19	598.50
	9	38.50	7	269.50
			$\underline{n} = 117$	$\bar{X} = 18.42$
June 15-Sept. 7, 1965	Juvenile	1.50	255	382.50
	Juv + PM ₄ ^a	3.75	320	1200.00
	1	5.25	32	168.00
	2	7.50	2	15.00
	3	10.50	1	10.50
	4	14.00	0	0.00
	5	18.00	0	0.00
	6	22.00	3	66.00
	7	26.00	5	130.00
	8	31.50	6	189.00
	9	38.50	0	0.00
			$\underline{n} = 624$	$\bar{X} = 3.46$

^aRefer to the key to the ages (Couplet 1) for explanation (Section 4.4).

Table 4.5. Mean ages of Pterognathus longimembris trapped in W during 1965.

Trapping Intervals	Age Class	$\bar{X}$ Age for Class (months)	Frequency (f)	$f\bar{x}$
Aug. 15- Sept. 7 (intermittent)	Juvenile	1.50	75	112.50
	Juv + PM ₄ ^a	3.75	1	3.75
	1	5.25	0	0.00
	2	7.50	0	0.00
	3	10.50	0	0.00
	4	14.00	1	14.00
	5	18.00	1	18.00
	6	22.00	4	88.00
	7	26.00	4	104.00
	8	31.50	2	63.00
	9	38.50	0	0.00
			$n = 88$	$\bar{X} = 4.58$

^aRefer to the key to the ages (Couplet 1) for explanation (Section 4.4).

($p \leq .10$).

The t-test was also used to determine the difference between means of animals trapped in 1965 (Table 4.3) where these differences were not obvious due to extreme departures. Logarithmic transformations for the data were necessary to approximate a normal distribution. These analyses indicate that $\bar{X}_1 = \bar{X}_2$ ($p \leq .10$) and $\bar{X}_3 = \bar{X}_4$ ($p \leq .05$), but $\bar{X}_1$ and $\bar{X}_2$ were obviously different from $\bar{X}_3$ and $\bar{X}_4$.

It was of interest to compare the mean ages of invaders during 1964 with those in 1965. The mean age of June (1964) invaders was not significantly different from the mean age of June (1965) invaders at $p = .10$. The mean ages of July, 1964 invaders and July, 1965 invaders; and the Aug., 1964 invaders and Aug.-Sept., 1965 invaders were obviously all different. It was also evident that the mean age of P. longimembris for the total 1964 invasion was significantly different from the total for 1965 (Table 4.4).

As indicated earlier a sample of P. longimembris was trapped from the natural population (Table 4.5) between Aug. 15 and Sept. 7, 1965 to compare the natural mean age with that of the animals invading the grid during the same period. Using the t-test, the mean age for W was not significantly different ($p \leq .05$) from that for the Aug.-Sept., 1965 invaders.

Table 4.6 enumerates the P. longimembris captured in the grid during the 1964 and 1965 trapping periods along with the ratios of males to females for the same periods. During the original trapping-out and invasion periods of 1964, males were trapped more frequently than females. Throughout the total 1964 invasion period 1.5 more males were trapped than females. In 1965 invading females were trapped more frequently than males in all periods except June and July. In the natural

Table 4.6. Sex ratios of Perognathus longimembris trapped in the grid.

Trapping Interval	Males	Females	Number of Males to Females
1964			
June 7-11	73	55	1.3
June 13-30	35	29	1.2
July 1-31	21	7	3.0
Aug. 1-25	15	12	1.2
June 13-Aug. 25	71	48	1.5
1965			
June 9-13	16	22	0.7
June 15-30	2	2	1.0
July 1-31	20	14	1.4
Aug. 15-Sept. 7	265	331	0.8
June 15-Sept. 7	287	347	0.8

population (W), trapped during Aug.-Sept., 1965, the numbers of females exceeded males by 1.1 to 1.

Invasion rates were reduced to mean ($\bar{X}$) animals per day for those species repeatedly collected from the grid (Tables 4.7 and 4.8). Although invasion rates are computed for D. merriami, D. microps, and O. torridus; only P. longimembris was collected in sufficient numbers to detect possible invasion trends.

Analyses of P. longimembris invasion rates were necessary to determine if significant differences existed or if apparent differences were the result of variation. The t-test was again used to test for these differences. These analyses indicated that invasion in 1964 was significantly ($p \leq .10$) greater in June than in July or Aug., but no significant difference was found between July and Aug. In 1965 the Aug.-Sept. invasion rate was obviously different from June and/or July, even though there was no significant difference between June and July ($p \leq .10$).

The invasion rate for the 1964 June invaders was compared with the 1965 June invaders and the means were found to be significantly different ($p \leq .10$). July invaders in 1964 and 1965 showed no significant difference. The rates for the Aug., 1965 and the Aug.-Sept., 1965 invaders were obviously different. The difference in total invasion rates for P. longimembris in 1964 and 1965 was also large enough that no test of significance was necessary.

The grid was not trapped from Aug. 1-14, 1965 and it may appear that the high invasion rate during Aug. and Sept. was due to invasion and settlement during that time. If the daily recapture record of P. longimembris from Aug. 15 to Sept. 7 (Table 4.9) is examined it is apparent that this is not the cause, since relatively few were captured

Table 4.7. Rates of invasion of Perognathus longimembris and Onychomys torridus in the grid.

Species and Trapping Intervals	Number of Animals Trapped	Days of Trapping	Small Mammals Per Day $\bar{X}$
<u>P. longimembris</u>			
1964			
June 13-30	64	18	3.56
July 1-31	28	31	.90
Aug. 1-25	27	25	1.08
June 13-Aug. 25	119	74	1.61
1965			
June 15-30	44	16	.25
July 1-31	34	31	1.10
Aug. 15-Sept. 7	596	24	24.83
June 15-Sept. 7	634	71	8.93
<u>O. torridus</u>			
1964			
June 13-30	15	18	.83
July 1-31	14	31	.45
Aug. 1-25	13	25	.52
June 13-Aug. 25	42	74	.57
1965			
June 15-30	2	16	.13
July 1-31	7	31	.23
Aug. 15-Sept. 7	6	24	.25
June 15-Sept. 7	15	71	.21

Table 4.8. Rates of invasion of Dipodomys microps and Dipodomys merriami in the grid.

Species and Trapping Intervals	Number of Animals Trapped	Days of Trapping	Small Mammals Per Day $\bar{X}$
<u>D. microps</u>			
1964			
June 13-30	28	24	1.17
July 1-31	20	31	.65
Aug. 1-25	6	25	.24
June 13-Aug. 25	54	74	.73
1965			
June 15-30	2	16	.13
July 1-31	0	31	.00
Aug. 15-Sept. 7	9	24	.38
June 15-Sept. 7	11	71	.16
<u>D. merriami</u>			
1964			
June 13-30	8	18	.44
July 1-31	7	31	.23
Aug. 1-25	10	25	.40
June 13-Aug. 25	25	74	.34
1965			
June 15-30	5	16	.31
July 1-31	6	31	.19
Aug. 15-Sept. 7	14	24	.58
June 15-Sept. 7	25	71	.35

on Aug. 15 and 16 while the influx began on Aug. 17. This influx continued to increase or stay at a high level through Sept. 7. If a large number of P. longimembris had invaded and settled during the non-trapping period, the Aug. 15 and 16 captures should have been greater than observed, with a decrease following. It appears from the data that the high invasion rate observed during Aug. and Sept. 1965 was not effected by settlement during Aug. 1-14.

During Aug.-Sept. it was apparent that invaders were moving into the grid faster than they were being removed with the trapping procedure being used (see Table 4.9, Sept. 2 and 3). Additional traps were placed in the grid to remove this buildup and after only two trap nights the daily catch of invaders returned to numbers more nearly approximating those for late Aug.

A summary of the numbers of small mammals marked on transects Q through V is given in Table 4.10. In Table 4.11 marked animals that were captured in the grid during the summer of 1965 are recorded. Of all invaders in 1965 only four individuals were found to have been marked. Of these, three were D. merriami (no known residents) and one P. longimembris, also not established as a resident of the outside transects.

4.6. Discussion

Knowledge of reproductive activity and how this activity reacts to the environment is essential in understanding age distribution and invasion rates. Hall (1946) recorded one litter per year for P. longimembris with pregnancies noted from early April through June, the greatest number in June. Duke (1957) stated that Perognathus may have two litters each year and that pregnancy is possible between early April and early July. Vegetative growth in 1965 was considerably more

Table 4.9. Perognathus longimembris invasion of the grid from Aug. 15 to Sept. 7, 1965.

Capture Date	Number Trapped
Aug. 15	10
16	8
17	20
18	20
19	13
20	17
21	13
22	24
23	22
24	25
25	28
26	22
27	30
28	24
29	21
30	18
31	24
Sept. 1	23
2	79
3	61
4	33
5	26
6	15
7	20

Table 4.10. Small mammals marked and released on transects Q through V.

Species	Transect of Capture	Marked from June 5 to August 30	
		Total Marked	Known Residents
<u>P. longimembris</u>	Q	26	12
	R	28	8
	S	25	9
	T	27	5
	U	23	9
	V	21	6
<u>D. merriami</u>	Q	2	1
	R	8	5
	S	7	4
	T	6	4
	U	10	6
	V	11	7
<u>D. microps</u>	Q	1	0
	R	2	1
	S	1	1
	T	6	5
	U	2	0
	V	3	2
<u>O. torridus</u>	Q	0	0
	R	1	1
	S	1	0
	T	0	0
	U	2	1
	V	0	0

Table 4.11. Marked small mammals invading the grid from Transects Q through V.

Species	Identifi- cation	Date Marked	Date Removed From the grid	Transect Marked On	Transect of Capture In the grid	Minimum Distance Traversed
<u>P. longimembris</u>	NEL-24	June 6	June 6	R	A	182.9 m
<u>D. merriami</u>	NEL-23	June 30	July 13	R	K	411.5 m
	RER-1	June 8	June 15	U	A	457.2 m
	RER-34	June 29	Aug. 19	U	A	457.2 m

luxuriant than in 1964, due possibly to the apparent increased available moisture (as evidenced by the rather showy desert flower bloom in spring and early summer). This would be in agreement with Lindeborg (1941) who found that Blarina and Peromyscus fluctuate directly with food abundance. The stipulation that this was the case at the test site is supported by Dr. Norman French (University of California, Los Angeles, California, personal communication) who observed rapid population growth among P. longimembris in a fenced grid near the test site during the middle and late summer of 1965. Additional reference to marked non-cyclic fluctuations (possibly due to food availability) in numbers were made by Blair (1948), Brown (1954), Andrzejewski (1963), and Sadleir (1965).

In 1964 (Table 4.2) and 1965 (Table 4.3) the decrease in mean age from the June invaders to that observed among the July and Aug. or Aug.-Sept. invaders correlates well with the appearance of young. The high mean age of P. longimembris trapped in all June periods may reflect the high mortality rate among juveniles, few surviving a full year. These observations agree with Blair (1948) and Brown (1954) who studied Peromyscus and found that the majority survive for only six months or less in their natural habitat. The difference between mean ages of invading P. longimembris in 1964 and 1965 (Table 4.4) may be due to the difference in mean ages of the natural populations during these two seasons. The extremely low mean age of invaders in July and Aug.-Sept. of 1965 correlates well with the greater reproductive activity of P. longimembris in 1965.

The mean age of the natural population of P. longimembris in W (Table 4.5) trapped from Aug. 15 to Sept. 17, 1965 was compared with that for the grid during the same period. Though the mean age of invaders into the grid appeared to be slightly lower than that of

the natural population (W) the difference was not significant. Thus, from these data it appears that all age groups have an equal tendency to invade a new area. These results suggest that the mean age of invaders may vary directly with that of the natural population. This observation was supported further by the fact that the average age of June invaders (1964) was not significantly different from that of the original population trapped from June 7-11, 1964. These data also aid in understanding the correlations in the preceding paragraph between lower mean age of invaders and reproductivity. These results were not expected prior to the sampling and were not the same as those observed by Sadlier (1965) who found that juvenile Peromyscus sought out void areas to avoid competition with adults.

Invasion rates are likely influenced by several population characters. Stickle (1946) noted that Peromyscus with some ranges overlapping nearest a void were first to invade. Andrzejewski and Wroclawek (1962) concluded that invasion rates of Apodemus and Clethrionomys were determined by the density of the adjacent population, and further, Andrzejewski (1963) stated that increased rates of invasion and settling during mid-summer were due primarily to emergence of young and subsequent increase of density.

Rates of invasion into the grid by P. longimembris apparently were influenced by both the border effect and the population density of the surrounding population. The highest rate in 1964 occurred from June 13-30 and was likely due to the rapid removal of animals with home ranges overlapping or adjacent to the grid. Since reproduction during 1964 was not especially prolific the invasion rate did not actually increase significantly, presumably because of the low density in the surrounding population. Almost the inverse occurred in 1965 when a low density

(resulting from the 1964 low reproduction) resulted in a very little invasion in June and July but increased dramatically in Aug. and Sept. as the numerous young increased the density of the surrounding population (Table 4.7). This points out an apparent discrepancy between the age analyses and the invasion rate data for 1965. According to the low mean age observed for invaders in July of 1965 the young were emerging in large numbers and composed a high percentage of all P. longimembris present in the natural population. This statement is based on the previously discussed results which indicated that the mean age of invaders and the natural population was approximately equal. From this evidence it seems that mass invasion of the grid should have begun in July. The most plausible explanation for the low July invasion rate is that an extremely low population density existed due to poor environmental conditions in 1964 and thus the density had to increase considerably before competition began. This competition would then cause emigration of less competitive individuals into areas of lower density. According to our data the point at which competition and ensuing emigration began was shortly after mid-Aug., 1965.

Stickle (1946) observed that Peromyscus invading a trapped-out grid consisted of 1.5 males per female while the natural population in the immediate area contained equal numbers of males and females. Males invading the grid outnumbered females in 1964 and similar results were obtained in the original population (Table 4.6). This ratio was not observed in 1965 when females invaded more frequently than males. The sex ratio of P. longimembris from the natural population (W) was compared with that from a similar period (Aug.-Sept. 1965) in the grid and ratios of males to female for both samples were almost identical. This indicates the sex ratios of invading P. longimembris are approxi-

mately the same as those in the natural populations.

According to Andrzejewski and Wroclawek (1962) Clethrionomys and Apodemus invading a trapped-out habitat come from unsettled members of the surrounding population and not from those settled on the periphery of the area. Stickel (1946), however, concluded that Peromyscus move into most voids from adjacent areas and are successively replaced by those farther out. This same conclusion was also reached by Calhoun and Webb (1953) working with Blarina, Clethrionomys, Peromyscus, and Sorex. Webb (1965) studying Clethrionomys, Microtus, Peromyscus, and Sorex, found that invaders come from those settled in peripheral areas and from unsettled (nomadic) members of the population. The results from Q through V (Table 4.11) indicated that settled animals in the peripheral areas of the grid had little tendency to invade since only four were trapped inside the grid. Of these four none had been established as known residents in the outside transect area.

Concerning P. longimembris, it was expected that a large number of marked animals would invade the grid. It is probable that a number of young emerged from their nests and emigrated from the transect area without being marked. The majority of this emigration would have taken place from Aug. 15 to Sept. 7, 1965 (Table 4.9). It is understood in inferring that large numbers of young may have emigrated that a high proportion of young were also in the population, and there was not a preferential emigration of young in relation to adults. It is postulated that a number of these unmarked emigrating P. longimembris may have invaded the grid.

The results from the home site origin studies are inconclusive but it appeared that the majority of small mammals invading the grid came from unsettled members of the population. These unsettled members

were not full time vagrants but individuals that were forced to leave their home site when density increased to the point where they could no longer compete. It could not be shown that previously settled small mammals moved into the area with these being successively replaced by those farther out. The only preferential invasion from settled animals in the immediate area appeared to be by those with home ranges actually overlapping the trapped-out area.

5. Reactions of Small Mammals to an Underground Nuclear Detonation

5.1. Introduction

Sedan provided biologists their first opportunity to gather basic ecological data on small mammals at the U. S. Atomic Energy Commission Nevada Test Site before the nuclear device had been detonated. Most nuclear weapons tests at the test site have been above ground where thermal radiation and shock waves were so detrimental that they overshadowed the effects of nuclear radiation on small mammals; or they were so deep that the tests did not vent, thus, having little effect on the surface. Sedan was designed so that thermal and initial radiation would be minimized and the effects of the shock wave and throw-out could be examined relatively close to ground-zero (GZ).

It will take many years to conclude observations on the overall effects of Sedan on small mammal populations. The objectives of this study are not quite as long range, being (1) to determine the kinds and populations of small mammals and the rate with which they reinhabit an area disturbed by a nuclear detonation, and (2) to determine the migrability of small mammals into and away from the disturbed area.

Certain plant-animal associations have been described for the Nevada Test Site by Allred and Beck (1963) and more comprehensively by Allred, Beck, and Jorgensen (1963). The latter distinguished the major biotic communities. Some of this work has been reported earlier by Jorgensen, Allred, and Beck, (1963).

5.2. Procedures

The area surrounding GZ was evaluated on the basis of previous ecological surveys which had been made for the area (partially reported

in Allred, Beck, and Jorgensen, 1963). On the basis of previous surveys, the area northeast of GZ was selected for the major part of this study. A study transect (57°30' azimuth) was established for intensive work (Fig. 5.1).

5.3. Vegetation Analyses

A modified line intercept method was used to determine the percentages of plant cover and composition. Pre-test analyses were made at distances of 229, 457, 610, 762, 915, 1067, 1220, 1372, 1524, 1829, 2134, 2439, and 2744 m from GZ. Since many of the plants were badly damaged by the detonation, and most were in a state of summer dormancy, it was not possible to make reliable species determinations of many plants closer than about 1220 m from GZ during the first summer following the test. A general evaluation of the damage was made, but a repeated station analysis was not made.

Vegetation was once again sampled in 1964, as the denuded area began to support vegetation. These samples were taken at 610, 915, 1220, and 1524 m from GZ.

5.4. Small Mammal Trapping Procedures

Trapping transects were established at certain distances from GZ, and at right angles to the study transect (Fig. 5.1). Each trapping transect was 457 m long and contained 21 Young-type small mammal traps placed 22.9 m apart. Three of the trapping transects were clustered at each of the following distances from GZ to form small grids for population surveys (Fig. 5.1).

305 m	Transects A,B,C,
610 m	Transects D,E,F,
915 m	Transects G,H,I,
1220 m	Transects J,K,L,
1524 m	Transects M,N,O,
2134 m	Transects P,R,S,
2744 m	Transects T,U,W.

Other trapping transects were placed between these grids to monitor movement of animals along the study transect. These are identified with double letters in Fig. 5.1. The traps were baited with oat-meal and surveys of the grids were made in June-July, 1962 (Pre-test); Aug.-Sept., 1962 (Post-Test); June, 1964; Sept., 1964; June, 1965; July, 1965; and Sept., 1965. The single trapping transects were operated only once, June-July, 1963, which was the pre-test survey. While in operation, all trapping transects were serviced once each day (early morning) and the following data recorded: station number, date, species, stage of development, sex, and marking (each animal was given a new mark if they were unmarked). Animals were marked with a combination of clipped ears and toes. Population numbers were determined with the method proposed by Hayne (1949).

5.5. Results of Vegetation Analyses

Two vegetation types were evident before the test. The first was a herbaceous zone which extended from GZ to about 991 m. It was characterized by Salsola kali, Sitanian hansenii, Oryzopsis hymenoides, and Mentzelia albicaulis. These species invaded this area as a consequence of past nuclear tests which destroyed the original shrubs. The second was a shrub zone which extended from 991 m outward from GZ. This zone was characterized by Coleogyne ramosissima, Grayia spinosa, and Lycium andersonii (Fig. 5.1 and Table 5.1).

The vegetation in the vicinity of GZ was altered considerably as a function of distance from GZ. This resulted in three new zones (Fig. 5.1). The first of these zones extended from GZ to about 915 m, within which the vegetation was apparently completely destroyed and there was a deposit of more than 30 cm of throw-out. The second zone extended from about 915 m to about 1524 m from GZ, where the vegetation

Table 5.1. Percentage of vegetative cover at intervals between 305 and 2744 m from GZ along the study transect prior to the detonation of Sedan (pre-test).

Species ^a	Meters from GZ								
	305	610	915	1220	1524	1829	2134	2439	2744
<u>Salsola kali</u>	56.65	29.09	1.34	1.48	1.14				
<u>Oryzopsis hymenoides</u>	16.71	21.01	12.83	8.14	10.02				
<u>Hilaria jamesii</u>	9.78	0.52	0.89						
<u>Sitanion hansenii</u>	4.75	8.23	13.13	11.48	0.88				3.19
<u>Mentzelia albicaulis</u>	3.53	9.45	10.89	2.22	1.64				
<u>Atriplex canescens</u>	4.89	8.40		2.77					
<u>Stephanomeria exigua</u>	3.66	5.60							
<u>Hymenoclea salsola</u>		12.60	18.35		9.64	15.05	3.54	1.60	
<u>Grayia spinosa</u>		3.15	12.23	19.62	25.12	22.72	12.74	15.26	32.51
<u>Eurotia lanata</u>		2.45	1.64						1.69
<u>Lycium andersonii</u>		1.75	9.85	3.88			4.53	14.85	6.39
<u>Happlopeppus cooperi</u>		0.70	0.89						6.39
<u>Menodora spinescens</u>			10.00	10.55			1.69		
<u>Coleogyne ramosissima</u>			2.98	34.62	51.52	58.80	73.32	65.06	47.18
<u>Acamptopappus schackleyi</u>			2.23						
<u>Stipa speciosa</u>			1.64						
<u>Ephedra nevadensis</u>			1.04	4.07		3.40	0.42		0.93
<u>Franseria dumosa</u>				1.11					
<u>Artemisia axillaris</u>							3.11		1.69
<u>Tetradymia canescens</u>								3.21	
Total Surface Cover	25.55	19.82	23.26	18.75	27.36	24.44	24.51	17.29	18.47

^aBotanical nomenclature from Beatley (1962).

was damaged by flying missiles, but the throw-out was generally rather shallow. Damage ranged from almost complete destruction near 915 m to slight damage at 1524 m. The third zone extended from about 1524 m outward. It was characterized by a distinct layer of dust, but no immediately visible blast damage to the plants.

The vegetation was again analysed in 1964 after the inner zones had some time to begin their recovery. Also, some of the plants which had previously been only damaged have since died. The summary of these analyses are presented in Table 5.2. A contrast of Tables 5.1 and 5.2 illustrates the changes that occurred. Essentially the grids at 915 and 1220 m from GZ had only Salsola kali in 1964; the grid at 1524 m underwent a change in composition and cover; while the outside grids were unchanged.

5.6. Results of the Small Mammal Trapping

The small mammal data were analyzed from three aspects: (1) what occurred within the seven grids (2) how did each species respond to the test and subsequent vegetation recovery, and (3) what movement occurred between grids. The results of the studies within the grids are presented in Tables 5.2-5.8. Changes in the small mammal composition which occurred as a result of the test can be seen simply by examining these tables. Two items must be examined when attempting to evaluate the effects of a nuclear disturbance on small mammal populations: (1) species diversity which is, in part, a measure of the niche diversity within the habitat, and (2) small mammal numbers, which seems to be an indication of community production. If the latter is to be of most value, it should include an estimate of biomass, but since this is not available in this study only the total numbers will be presented.

Table 5.2. Percentage of vegetation cover during 1964 at intervals between 610 and 2744 m from GZ along the study transect.

Species ^a	Meters from GZ							
	610	915 ^b	1220 ^c	1524 ^d	1829	2134	2439	2744
<u>Salsola kali</u>	100.00	96.70	96.23	24.79				
<u>Oryzopsis hymenoides</u>		1.77	3.77	3.89				
<u>Sitanion hansenii</u>				.41				3.19
<u>Sphaeralcea</u> sp.		1.53						
<u>Chrysothamnus viscidiflorus</u>				1.94				
<u>Coleogyne ramosissima</u>				64.34	58.80	73.32	65.06	47.18
<u>Ephedra nevadensis</u>				2.92	3.40	0.42		0.93
<u>Stipa speciosa</u>				0.55				
<u>Hymenoclea salsola</u>				0.41	15.05	3.54	1.60	
<u>Menodora spinescens</u>				0.75		1.69		
<u>Grayia spinosa</u>					22.72	12.74	15.26	32.51
<u>Lycium andersonii</u>						4.53	14.85	6.39
<u>Haplopappus cooperi</u>								6.39
<u>Artemisia axillaris</u>						3.11		1.69
<u>Tetradymia canescens</u>							3.21	
<u>Eurotia lanata</u>								1.69
Total Surface Cover	19.39	16.41	20.45	14.95	24.44	24.51	17.29	18.47

^aBotanical nomenclature from Beatley (1962).

^bSpecies observed, but not included in the samples are: Lycium andersonii, Atriplex canescens, Franeria dumosa, and Eriogonum sp.

^cSpecies observed, but not included in the samples are: Lycium andersonii, Atriplex canescens, Franeria dumosa, Eriogonum sp., Coleogyne ramosissima, Sphaeralcea sp., and Hymenoclea salsola.

^dSpecies observed, but not included in the samples are: Yucca brevifolia, Lycium andersonii, and Atriplex canescens.

Table 5.2. Small mammal trapping results within the grid located 305 m from Sedan GZ.

Species	Estimated Number of Individuals						
	Pre-Test	Post Test	June 1964	Sept. 1964	June 1965	July 1965	Sept. 1965
<u>Dipodomys merriami</u>	4.4	--	0	0	4.0	6.0	0
<u>Dipodomys microps</u>	1.0	--	0	0	0	0	0
<u>Dipodomys ordii</u>	2.0	--	0	0	15.1	15.7	14.4
<u>Onychomys torridus</u>	2.5	--	0	0	0	0	0
<u>Peromyscus maniculatus</u>	0	--	0	0	4.0	1.0	0
<u>Perognathus longimembris</u>	59.9	--	0	0	1.0	3.0	0
<u>Perognathus parvus</u>	4.9	--	0	0	0	0	0
Total	74.7	--	0	0	24.1	25.7	14.4
Diversity Index (<u>d</u>)	.66	--	--	--	.44	.44	.11

Table 5.3. Small mammal trapping results within the grid located 610 m from Sedan GZ.

Species	Estimated Number of Individuals						
	Pre-Test	Post Test	June 1964	Sept. 1964	June 1965	July 1965	Sept. 1965
<u>Dipodomys merriami</u>	5.6	--	0	15.5	25.5	46.8	6.8
<u>Dipodomys microps</u>	1.00	--	0	0	0	0	0
<u>Dipodomys ordii</u>	1.0	--	0	0	19.2	65.0	14.0
<u>Onychomys torridus</u>	0	--	0	0	0	1.0	1.0
<u>Peromyscus crinitus</u>	0	--	1.0	1.0	0	0	0
<u>Peromyscus maniculatus</u>	0	--	0	0	0	1.0	1.0
<u>Perognathus longimembris</u>	56.0	--	1.0	2.0	1.5	2.7	8.6
<u>Perognathus parvus</u>	4.6	--	0	0	0	0	0
Total	68.2	--	2.0	18.5	46.2	116.5	31.4
Diversity Index (d)	.55	--	.22	.33	.33	.55	.55

Table 5.4. Small mammal trapping results within the grid located 915 m from Sedan GZ.

Species	Estimated Number of Individuals						
	Pre-Test	Post-Test	June 1964	Sept. 1964	June 1965	July 1965	Sept. 1965
<u>Dipodomys merriami</u>	4.0	0	0	0	15.8	30.0	31.7
<u>Dipodomys microps</u>	2.0	1.0	0	0	0	0	0
<u>Dipodomys ordii</u>	1.0	0	0	0	1.0	1.0	5.2
<u>Onychomys torridus</u>	5.0	1.0	0	1.0	0	1.0	0
<u>Peromyscus maniculatus</u>	0	0	0	0	1.0	0	0
<u>Perognathus longimembris</u>	91.0	4.5	2.0	6.0	3.0	2.0	4.4
<u>Perognathus parvus</u>	8.8	0	0	0	0	0	0
Total	111.8	6.5	2.0	7.0	20.8	34.0	41.3
Diversity Index (<u>d</u>)	.66	.33	.11	.22	.44	.44	.33

Table 5.5. Small mammal trapping results within the grid located 1220 m from Sedan GZ.

Species	Estimated Number of Individuals						
	Pre-Test	Post-Test	June 1964	Sept. 1964	June 1965	July 1965	Sept. 1965
<u>Dipodomys merriami</u>	9.6	1.0	1.0	2.0	71.1	41.8	67.0
<u>Dipodomys microps</u>	9.9	1.0	24.4	84.8	6.0	0	0
<u>Dipodomys ordii</u>	0	0	0	0	6.6	22.0	64.7
<u>Onychomys torridus</u>	1.0	1.0	1.0	1.0	1.0	1.0	1.0
<u>Peromyscus crinitus</u>	0	0	0	1.0	0	0	0
<u>Peromyscus maniculatus</u>	0	0	0	0	1.0	0	0
<u>Perognathus longimembris</u>	52.4	1.0	2.0	1.0	3.0	1.0	11.2
<u>Perognathus parvus</u>	1.0	0	0	0	0	0	0
Total	73.9	4.0	28.4	89.8	88.7	65.8	143.8
Diversity Index (<u>d</u>)	.55	.44	.44	.55	.66	.44	.44

Table 5.6. Small mammal trapping results within the grid 1524 m from Sedan GZ.

Species	Estimated Number of Individuals						
	Pre- Test	Post Test	June 1964	Sept. 1964	June 1965	July 1965	Sept. 1965
<u>Amnospermophilus leucurus</u>	0	0	1.0	44.0	0	--	1.0
<u>Dipodomys merriami</u>	3.1	2.0	37.9	120.8	9.4	--	67.8
<u>Dipodomys microps</u>	7.6	28.2	5.0	1.0	1.0	--	0
<u>Onychomys torridus</u>	5.0	0	0	1.0	1.0	--	1.0
<u>Peromyscus crinitus</u>	0	0	0	0	1.0	--	0
<u>Perognathus longimembris</u>	95.2	0	101.3	17.7	54.4	--	12.5
<u>Perognathus parvus</u>	1.0	1.0	0	0	0	--	0
Total	111.9	31.2	145.20	184.5	65.8	--	82.3
Diversity Index (d)	.55	.33	.44	.55	.55	--	.44

Table 5.7. Small mammal trapping results within the grid 2134 m from Sedan GZ.

Species	Estimated Number of Individuals						
	Pre-Test	Post test	June 1964	Sept. 1964	June 1965	July 1965	Sept. 1965
<u>Amnospermophilus leucurus</u>	0	0	29.0	37.0	1.0	--	18.3
<u>Dipodomys merriami</u>	0	0	2.0	5.0	1.0	--	14.8
<u>Dipodomys microps</u>	20.7	26.4	4.2	33.9	9.4	--	3.2
<u>Onychomys torridus</u>	1.0	1.0	0	0	0	--	0
<u>Perognathus longimembris</u>	36.8	90.3	26.3	28.5	49.2	--	14.2
<u>Perognathus parvus</u>	1.0	0	1.0	0	0	--	2.5
Total	59.5	117.7	62.5	104.4	60.6	--	53.0
Diversity Index (d)	.44	.33	.55	.44	.44		.55

Table 5.7. Small mammal trapping results within the grid 2744 m from Sedan GZ.

Species	Estimated Number of Individuals						
	Pre-Test	Post test	June 1964	Sept. 1964	June 1965	July 1965	Sept. 1965
<u>Ammospermophilus leucurus</u>	0	0	31.0	43.0	2.0	--	39.2
<u>Dipodomys merriami</u>	0	0	10.0	0	13.0	--	4.7
<u>Dipodomys microps</u>	22.4	51.1	14.1	27.9	4.7	--	2.0
<u>Onychomys torridus</u>	1.0	1.0	1.0	5.0	1.0	--	1.0
<u>Peromyscus maniculatus</u>	0	0	0	0	0	--	1.0
<u>Perognathus longimembris</u>	66.4	61.7	24.0	53.5	90.0	--	20.4
Total	89.8	113.8	80.1	129.4	110.7	--	68.3
Diversity Index (<u>d</u>)	.32	.33	.55	.44	.55	--	.66

Species diversity may be expressed simply in terms of numbers of kinds present, but since the primary concern of this report is relative to the distance from GZ, an index has been developed. This index is expressed as:

$$\underline{d} = \underline{s}/\underline{t} \quad (6.1)$$

where $\underline{d}$ = index of species diversity,
 $\underline{s}$ = number of species present at a single sample period,
 $\underline{t}$ = number of species that have been trapped in all grids through all sample periods.

When one attempts to examine the effects of a nuclear detonation on individual species of small mammals, all of the grids should be reviewed at once. The data have been organized for this purpose in Tables 5.8-15.

Only two animals marked before the test (Dipodomys microps) were found in grids other than those they were marked in. In both cases they had moved from the grid at 2744 m to the grid at 2134 m. These two grids are in the post-test Zone-3 which showed no visible effects of the test. Apparently the disturbance resulting from Sedan did not cause an immediate or even long-term movement of small mammals away from the area of destruction.

5.7. Discussion

Sedan was detonated in the northern portion of Yucca Flat where the native vegetation before the advent of nuclear weapons testing was probably predominantly Coleogyne ramosissima, Grayia spinosa, and Lycium andersonii. Sedan GZ was surrounded almost entirely by a herbaceous vegetation and dominated by Salsola kali (Fig. 5.1 and Table 5.1). This zone resulted from tests which were conducted before the 1958 moratorium on above-ground nuclear weapons testing. The herbaceous

Table 5.8. Summary of Ammospermophilus leucurus trapped along the Sedan study transect.

Distance from GZ	Estimated Number of Individuals						
	Pre-Test	Post test	June 1964	Sept. 1964	June 1965	July 1965	Sept. 1965
305 m	0	--	0	0	0	0	0
610 m	0	--	0	0	0	0	0
915 m	0	0	0	0	0	0	0
1220 m	0	0	0	0	0	0	0
1524 m	0	0	1.0	44.0	0	--	0
2134 m	0	0	29.0	37.0	1.0	--	18.3
2744 m	0	0	31.0	43.0	2.0	--	39.2

Table 5.9. Summary of Dipodomys merriami trapped along the Sedan study transect.

Distance from GZ.	Estimated Number of Individuals						
	Pre- test	Post test	June 1964	Sept. 1964	June 1965	July 1965	Sept. 1965
305 m	4.4	--	0	0	4.0	6.0	0
610 m	5.6	--	0	15.5	25.1	46.8	6.8
915 m	4.0	0	0	0	15.8	30.0	31.7
1220 m	9.6	1.0	1.0	2.0	71.1	41.8	67.0
1524 m	3.1	2.0	37.9	120.8	9.4	--	67.8
2134 m	0	0	2.0	5.0	1.0	--	14.8
2744 m	0	0	10.0	0	13.0	--	4.7

Table 5.10. Summary of Dipodomys microps trapped along the Sedan study transect.

Distance from GZ	Estimated Number of Individuals						
	Pre-test	Post test	June 1964	Sept. 1964	June 1965	July 1965	Sept. 1965
305 m	1.0	--	0	0	0	0	0
610 m	1.0	--	0	0	0	0	0
915 m	2.0	1.0	0	0	0	0	0
1220 m	9.9	1.0	24.4	84.8	6.0	0	0
1524 m	7.6	28.2	5.0	1.0	1.0	--	0
2134 m	20.7	26.4	4.2	33.8	9.4	--	3.2
2744 m	22.4	51.1	14.1	26.9	4.7	--	2.0

Table 5.11. Summary of Dipodomys ordii trapped along the Sedan study transect.

Distance from GZ	Estimated Number of Individuals						
	Pre-test	Post test	June 1964	Sept. 1964	June 1965	July 1965	Sept. 1965
305 m	2.0	--	0	0	15.1	15.7	14.4
610 m	1.0	--	0	0	19.2	65.0	14.0
915 m	1.0	0	0	0	1.0	1.0	5.2
1220 m	0	0	0	0	6.6	22.0	64.7
1524 m	0	0	0	0	0	--	0
2134 m	0	0	0	0	0	--	0
2744 m	0	0	0	0	0	--	0

Table 5.12. Summary of Onychomys torridus trapped along the Sedan study transect.

Distance from GZ	Estimated Number of Individuals						
	Pre- test	Post test	June 1964	Sept. 1964	June 1965	July 1965	Sept. 1965
305 m	2.5	--	0	0	0	0	0
610 m	0	--	0	0	0	1.0	1.0
915 m	5.0	1.0	0	1.0	0	1.0	1.0
1220 m	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1524 m	5.0	0	0	1.0	1.0	--	1.0
2134 m	1.0	1.0	0	0	0	--	0
2744 m	1.0	1.0	0	5.0	1.0	--	1.0

Table 5.13. Summary of Peromyscus crinitus and Peromyscus maniculatus trapped along the Sedan study transect.

Distance from GZ	Estimated Number of Individuals						
	Pre-test	Post test	June 1964	Sept. 1964	June 1965	July 1965	Sept. 1965
305 m	0	--	0	0	0	4.0 ^b	1.0 ^b
610 m	0	--	1.0 ^a	1.0 ^a	0	1.0 ^b	1.0 ^b
915 m	0	0	0	0	1.0 ^b	0	0
1220 m	0	0	0	1.0 ^a	1.0 ^b	0	0
1524 m	0	0	0	0	1.0 ^a	--	0
2134 m	0	0	0	0	0	--	0
2744 m	0	0	0	0	0	--	1.0 ^b

^aPeromyscus crinitus

^bPeromyscus maniculatus

Table 5.14. Summary of Perognathus longimembris trapped along the Sedan study transect.

Distance from GZ	Estimated Number of Individuals						
	Pre-test	Post test	June 1964	Sept. 1964	June 1965	July 1965	Sept. 1965
305 m	59.9	--	0	0	1.0	3.0	0
610 m	56.0	--	1.0	2.0	1.5	2.7	8.6
915 m	91.0	4.5	2.0	6.0	3.0	2.0	4.4
1220 m	52.4	1.0	2.0	1.0	3.0	1.0	11.2
1524 m	95.2	0	101.3	17.73	54.4	--	12.5
2134 m	36.8	90.29	26.3	28.5	49.2	--	14.2
2744 m	66.4	61.67	24.0	53.5	90.0	--	20.4

Table 5.15. Summary of Perognathus parvus trapped along the Sedan study transect.

Distance from GZ	Estimated Number of Individuals						
	Pre-test	Post test	June 1964	Sept. 1964	June 1965	July 1965	Sept. 1965
305 m	4.9	--	0	0	0	0	0
610 m	4.6	--	0	0	0	0	0
915 m	8.8	0	0	0	0	0	0
1220 m	1.1	0	0	0	0	0	0
1524 m	1.0	1.0	0	0	0	--	0
2134 m	1.0	0	1.0	0	0	--	2.5
2744 m	0	0	0	0	0	--	0

vegetation merged with shrubby plants along the Sedan study transect at about 991 m from GZ.

Shields and Wells (1962) described the recovery of vegetation in areas at the Nevada Test Site which were previously denuded by nuclear weapons tests. They discussed the invasion of vast stands of Salsola kali associated with other annual and perennial herbs. With these primary plant invaders came certain invertebrates in large numbers. Small mammals also invade when sufficient food becomes available. The disturbed area surrounding Sedan GZ follow the type of plant succession described by Shields and Wells (1962) almost precisely. Salsola kali was the primary invader of the disturbed areas and in 1964 was about the only species found close to the crater created by the test.

Many small mammals are characteristically associated with certain plant associations. Jorgensen and Hayward (1965) found that A. leucurus, D. merriami, D. ordii, and P. longimembris were frequently abundant in Salsola biotic communities, whereas numerous other species are only occasionally collected. They found D. merriami, D. microps, P. formosus, and P. longimembris rather abundant in Coleogyne biotic communities. Similar results were obtained while studying the effects of Sedan. Small mammal populations varied, prior to the test, between the vegetative zones in the vicinity of GZ. Dipodomys merriami, D. ordii, and P. parvus were more abundant in the herbaceous zones. Dipodomys microps was more abundant in the shrub zone, and A. leucurus and O. torridus were each about equally numerous within each zone. Perognathus longimembris was the most abundant species at all distances from GZ and may furnish the most reliable species to study the test effects.

The small mammal composition within the grids in post-test Zones 1 and 2 changed considerably after the test, particularly as the area

began to revegetate. The grid at 305 m was occupied primarily by D. merriami, P. longimembris, and P. parvus before the test, but D. merriami and D. ordii predominated after revegetation began. Similar results were observed in the grid 610 m from GZ except P. longimembris was also common after the test. This was also the case in the grid at 915 m. All of these grids are located in post-test Zone 1 where tremendous damage was sustained. There was apparently an indication that both species diversity and animal production went through similar changes. They were reduced after the test when vegetation was scarce and revegetation was only beginning, but began to increase again in 1965.

The grids inside post-test Zones 2 and 3 generally remained about the same with respect to small mammal composition, except D. microps was generally reduced in 1965. This may have been in response to a corresponding increase in D. merriami, which was competing for available space. There were no apparent changes in species diversity or small mammal production although there was an indication of a slight reduction in the post-test estimates for the grid 1524 m from GZ.

An examination of individual species responses may provide the most meaningful information. Since the data for P. longimembris are most extensive and it was the most nearly ubiquitous, this species will be discussed first and subsequent discussions related to it. Table 5.14 illustrates some interesting figures that merit explanation. Generally, the grids which were damaged most (305 m, 610 m, 915 m, 1220 m) demonstrated a common trend. The animals were killed either directly or indirectly by the test and populations were reestablished by invading animals from outside, but only after revegetation was apparent. Also, it is likely, since inner population pressure is necessary to initiate substantial movement, that substantial invasion

had to wait for such pressures to occur in the surrounding areas. Adult males and females would most likely make up the majority of the invaders even though immature forms would certainly be present.

The grid 1524 m from GZ provided an estimate (0) during the post-test sampling that should be given some attention. There was considerable damage to some vegetative components at this distance, particularly Grayia spinosa and Hymenoclea salsola. Since P. longimembris has the capability of estivating during unfavorable times of the late summer, it is proposed that these animals simply were not active during that sampling time. Whereas, at distances further away, they retained their activity since the damage was not so extensive as to initiate estivation behavior. Animals that were active closer to GZ may have been forced into activity by the unsettled nature of the new habitat.

Perognathus parvus was essentially eliminated by the test although a few persisted 2134 m from GZ (Table 5.15). This is apparently a response to a change in their habitat, making it no longer suitable for them.

Peromyscus crinitus and P. maniculatus were collected so infrequently that suggestions of their responses are untenable (Table 5.13). Onychomys torridus was generally always collected, even in the post-test sample, but they appeared to avoid the closer grids following the test (Table 5.12).

Dipodomys ordii made a most significant recovery following the test, but only after revegetation had occurred (Table 5.11). This species was collected only from the immediate vicinity of GZ before the test, and this is where it persisted after the test. Because of its pre-test distribution, one would think that it should have been eliminated along with P. parvus. Since D. ordii was not collected outside of post-test

Zone 1 before the test, it is thought they must have survived the test in numbers so small that they were not collected in 1964, but built up rather large numbers in 1965. Also, the habitat available in depressions filled with Salsola appears to be favorable for these kangaroo rats.

Dipodomys microps was apparently eliminated from post-test Zone 1, although it was quite sparse in this region before the test (Table 5.10). There was a general decline in their numbers in the outside grids, and this may have influenced their lack of invasion, since internal population pressures would have been negligible.

It is difficult to assess the reactions of D. merriami to the test since they generally increased after the test in all of the grids. This, of course, followed a low period during the post-test sampling period (Table 5.9). Generally, they appeared to prefer the transition between the herbaceous zone and the shrub zone before the test, and maintained a similar position in post-test Zone 2 after the test.

The sampling techniques were not adequate to give reliable data for A. leucurus, thus interpretations of the data in Table 5.8 are not feasible.

6. Some Effects of an Underground Nuclear Detonation on Certain Invertebrates

6.1. Introduction

The overall justification and layout for this section is the same as that for Section 5. The animals included in these samples were limited to the ground dwellers since they seemed to be more prominent than others.

6.2. Methods

Initially, buried pit-can traps were placed along the entire length of the Sedan study transect. Their precise position is indicated on Fig. 5.1. Data were gathered with this design during the pre-and post-test samples, but proved to be of little use since the effort was not concentrated sufficiently at any one particular spot.

The trapping design was then changed to include three pit-can trap grids which contained 25 traps each, placed 3 m apart. These grids were located 610, 1220, and 2439 m from GZ. They were serviced for 10 continuous days each month; June, July and Aug., 1964, and June and Aug., 1965. Collected specimens were retained in 70% ethyl alcohol until they could be identified. Only a few species that appeared useful in evaluating their reaction to an underground nuclear detonation were selected from these collections.

6.3. Results

The results of the samples described in Section 6.2 are presented in Tables 6.1, 6.2, and 6.3. Although numerous species were collected, only a few were analysed since most were only incidental collections. Generally, it appears that several species have specific requirements, and when these are altered, their numbers respond accordingly. Another

observation that is apparent is the tremendous differences between years, doubtlessly due to a complex of factors.

Table 6.1. Summary of the invertebrates collected from the grid 610 m from Sedan GZ.

Species	1964			1965	
	June	July	Aug.	June	Aug.
<u>Eleodes</u> sp.	16	15	20	38	63
<u>Eusattus</u> <u>dubius</u>	0	7	54	0	41
<u>Edrotes</u> sp.	1	1	6	23	8
<u>Trogloderus</u> <u>costatus</u>	8	3	1	1	8
<u>Pelecyporus</u> sp.	0	1	0	0	5
<u>Stenopelmatus</u> <u>fuscus</u>	1	1	0	0	5
<u>Globipes</u> <u>spinulatus</u>	0	2	2	0	5
<u>Anuroctonus</u> <u>phaedactylus</u>	0	0	0	0	13
<u>Vejovis</u> sp.	29	9	9	1	5

Table 6.2 Summary of the invertebrates collected from the grid
1220 m from Sedan GZ.

Species	1964			1965	
	June	July	Aug.	June	Aug.
<u>Eleodes</u> sp.	2	11	5	13	13
<u>Eusattus dubius</u>	1	3	0	0	39
<u>Edrotes</u> sp.	3	4	1	2	2
<u>Trogloderus costatus</u>	27	6	34	1	7
<u>Pelecyporus</u> sp.	0	0	3	0	21
<u>Stenopelmatus fuscus</u>	6	4	1	2	0
<u>Globipes spinulatus</u>	1	4	2	1	3
<u>Anuroctonus phaeodactylus</u>	0	0	1	0	2
<u>Vejovis</u> sp.	11	3	5	2	7

Table 6.3. Summary of the invertebrates collected from the grid
2409 m from Sedan GZ.

Species	1964			1965	
	June	July	Aug.	June	Aug.
<u>Eleodes</u> sp.	4	7	5	13	10
<u>Eusattus dubius</u>	0	0	0	0	4
<u>Edrotes</u> sp.	0	0	0	1	0
<u>Trogloderus costatus</u>	0	0	0	0	0
<u>Pelecyporus</u> sp.	0	0	5	0	94
<u>Stenopelmatus fuscus</u>	2	0	0	0	0
<u>Globipes spinulatus</u>	18	7	8	7	0
<u>Anurectonus phaeodactylus</u>	8	6	3	3	12
<u>Vejovis</u> sp.	18	4	4	5	7

7. Conclusions

Many specific conclusions could be adopted from this study, but the intent of this section is to present some general conclusions that pertain specifically to an underground nuclear detonation. These conclusions are formed as a composite examination of all preceding sections in this report.

7.1.

Reactions of small mammals and certain selected invertebrates to the test are similar to what one would expect for any type of physical disturbance to the soil and vegetation. Simple plowing at varying depths from a point source would likely result in similar reactions by these animals.

7.2.

The reactions of animals are frequently secondary, being a function of the vegetation response. Thus it may be very rapid in some cases and may require several years in others, as the vegetation continues to integrate the test effects with naturally occurring environmental factors.

7.3.

Animals invade the disturbed areas only after the vegetation begins to recover and provide food and cover. The animal species may be very different than what originally occupied the area since only those adapted to the new environment persist.

7.4.

If animal populations are restricted to the areas of heaviest disturbance, they may be eliminated entirely.

7.5.

Some species may be forced into early estivation. This reaction would

be expected only if the season is well advanced. Survival would be enhanced by this behavior, but only if there is sufficient habitat suitable for them after they emerge from their estivation.

7.6.

There is generally a selective response to varying degrees and types of community damage, thus certain species will survive while others will not. The survivors may or may not become the dominant species in subsequent successional development of the disturbed areas.

7.7.

Invasion by small mammals occurs only when population pressures surrounding the damaged areas are sufficient to force animals into broader searching habits. Both young and adults would be expected to participate in the invasion. Internal stress factors may be measured in terms of the probability that one animal will interact with another.

7.8.

Invasion behavior and successional development after a test is not necessarily altered by the fact that the damage is caused by a nuclear detonation although there is likely to be some early radiation effects on the vegetation which could secondarily affect certain insect species closely tied to specific host plants.

8. Literature Cited

- Allred, D. M. and D. E. Beck. 1963. Ecological distribution of some rodents at the Nevada Atomic Test Site. *Ecology* 44: 211-214.
- Allred, D.M., D.E. Beck, and C. D. Jorgensen, 1963. Biotic communities of the Nevada test site. *Brigham Young Univ. Sci. Bull., Biol. Serv.* 2(2):1-52.
- Andrzejewski, R. 1963. Processes of incoming, settlement and disappearance of individuals and variations in the numbers of small rodents. *Acta Theriologica* 7:169-213.
- Andrzejewski, R. and H. Wroclawek. 1962. Settling by small rodents a terrain in which catching out had been performed. *Acta Theriologica* 6:257-273.
- Beatley, J.C. 1962. Vascular plants of the U. S. Atomic Energy Commission's Nevada test site, Nye County, Nevada. *Univ. Calif., Los Angeles Publ. No.* 508.
- Blair, W.F. 1940. A study of prairie deer mouse populations in southern Michigan. *Am. Midl. Nat.* 24:257-273.
- Blair, W.F. 1948. Population density, life span, and mortality rates of small mammals in the blue-grass meadow and blue-grass field association of southern Michigan. *Am. Midl. Nat.* 40:395-419.
- Box, G. E. P. and D. R. Cox. 1964. An analysis of transformation. *J. Roy. Statist. Soc. Ser. V. Vol.* 26.
- Brandt, D.H. 1962. Measures of the movements and population densities of small rodents. *Univ. Calif. Publ. Zool.* 62:105-184.
- Brown, L. E. 1954. Small mammal populations at Silwood Park Field Centre, Berkshire, England. *J. Mammal.* 35:161-176.
- Burt, W. H. 1943. Territoriality and home range concepts as applied to mammals. *J. Mammal.* 24:346-352.
- Calhoun, J. B. 1962. The ecology and sociology of the Norway rat. *U. S. Public Health. Ser. Publ.* 1008. 288 pp.
- Calhoun, J. B. 1963. The social use of space. In *Physiological Mammalogy Vol. 1* (ed. M. V. Meyer and R. G. Van Gelder). Academic Press, New York. p. 1-187.
- Calhoun, J. B. and J. N. Casby. 1958. Calculation of home range and density of small mammals. *U. S. Public Health. Monograph* 55: 1-24.
- Calhoun, J. B. and W. L. Webb. 1953. Induced emigrations among small mammals. *Science* 117:358-360.

- Dice, L. R. and P. J. Clark. 1953. The statistical concept of home range as applied to the recapture radius of the deermouse (Peromyscus) Contrib. Lab. Ver. Zool. No. 62:1-23.
- Duke, K. L. 1957. Reproduction in Perognathus. J. Mammal. 38:207-210.
- Elton, C. 1932. Territory among wood ants (Formica rufa L.) at Pickett Hill. J. Animal Ecol. 1:69-76.
- Hall, E. R. 1946. Mammals of Nevada. Univ. Calif. Press, Berkeley: 710 pp.
- Hamdan, M. A. 1963. The number and width of classes in the chi-square test. J. Am. Statist. Assoc.
- Harrison, J. L. 1958. Range of movement of some Malayan rats. J. Mammal. 39:190-206.
- Hayne, D. W. 1949. Calculation of size of home range. J. Mammal. 30:1-18.
- Hayne, D. W. 1949. Two methods for estimating population from trapping records. J. Mammal. 30:399-411.
- Jackson, W. B. and R. L. Strecker. 1962. Home range studies. Pacific Island ecology. Bernice P. Bishop Mus. Bull. 225:113-123.
- Jorgensen, C. D., D. M. Allred, and D. E. Beck. 1963. Some effects of an underground nuclear detonation on biotic communities at the Nevada test site. Proc. Utah Acad. Sci., Arts, Letters 40:49-61.
- Jorgensen, C. D. and C. L. Hayward. 1965. Mammals of the Nevada test site. Brigham-Young Univ. Sci. Bull., Biol. Ser. 6(3):1-81.
- Jorgensen, C. D. and W. W. Tanner. 1963. The application of the density probability function to determine the home ranges of Uta stansburiana stansburiana and Cnemidophorus tigris tigris. Herpetologica 19:105-115.
- Jorgensen, C. D. 1962. Disturbance of mammal traps by jack-rabbits. Great Basin Nat. 22:83-86.
- Lindeborg, R. G. 1941. Fluctuations in the abundance of small mammals in East-Central Illinois. Ecology 22:96-99.
- Mendenhall, W. 1963. Introduction to statistics. Wadsworth Publ. Co., Belmont, Calif. 305 pp.
- Mohr, C. O. 1956. Comparative infestations by ectoparasites of two native rats of Sansapor, New Guinea. Am. Midl. Nat. 55:382-392.
- Mohr, C. O. and W. S. Stumpf. 1964. Relation of tick and chigger infestations to home areas of California meadow mice. J. Med. Entomol. 1:73-77.

- Ostle, B. 1963. Statistics in Research. Iowa State Univ. Press Ames: 585 pp.
- Owen, D. B. 1957. Distribution-free tolerance limits. Sandia Corp. Tech. Mem. SCTM 66A-57-51. Sandia Corp. Albuquerque, New Mexico.
- Sadleir, R. M. 1965. The relationship between agnostic behavior and population changes in deermouse, Peromyscus maniculatus (Wagner) J. Anim. Ecol. 34:331-352.
- Shields, L. M. and P. V. Wells. 1962. Effects of nuclear testing on desert vegetation. Science 135:38-40.
- Snedecor, G. W. 1946. Statistical methods applied to experiments in agriculture and biology, 4th ed. Iowa State College Press, Ames. 485 p.
- Spencer, D. A. 1941. A small mammal community in the upper sonoran desert. Ecology 22:421-425.
- Stickel, L. F. 1946. The source of animals moving into a depopulated area. J. Mammal. 27:301-307.
- Stumpf, W. A. and C. O. Mohr. 1962. Linearity of home ranges of California mice and other animals. J. Wildl. Mgmt. 26:149-154.
- Tinkle, D. W. and D. McGregor, and D. Summer. 1962. Home range ecology of Uta stansburiana stejnegeri. Ecology 43:223-229.
- Webb, W. L. 1965. Small mammal populations on islands. Ecology 46: 479-488.