Results of Research to Develop Cost Effective Biomonitoring at Oil Shale Lease Tracts: Phase I Fall Sampling Report

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May 1982

**Prepared for
the U.S. Geological Survey
under a Related Services Agreement
with the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
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PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151

NTIS Price Codes
Microfiche A01

Printed Copy

Pages	Price Codes
001-025	A02
026-050	A03
051-075	A04
076-100	A05
101-125	A06
126-150	A07
151-175	A08
176-200	A09
201-225	A010
226-250	A011
251-275	A012
276-300	A013

RESULTS OF RESEARCH TO DEVELOP COST
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LEASE TRACTS: PHASE I
FALL SAMPLING REPORT

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RESULTS OF RESEARCH TO DEVELOP COST EFFECTIVE BIOMONITORING
AT OIL SHALE LEASE TRACTS:
PHASE I FALL SAMPLING REPORT

INTRODUCTION

The purpose of Pacific Northwest Laboratory's (PNL's) ecological research at Piceance Basin, Colorado is to evaluate the feasibility of monitoring small mammal and avifauna populations by determining the levels of field effort required to detect reasonable changes in abundance which may result from oil shale development. In addition, where total sampling costs are not prohibitive, to provide statistically sound monitoring schemes based on costs and field data.

The objective of the Fall 1981 research was to initiate a faunal sampling program. The fall census period is conceptualized as the beginning of a two-phased research program to design monitoring schemes to test for impacts on small mammal and avifauna populations that might result from oil shale development at federal lease tracts. The purpose of the first phase of the program, of which this report on the fall sampling is part, is to conduct faunal censuses to estimate variance components needed to properly design monitoring studies and to test the validity of both indices and absolute abundance estimators (Seber 1973). The second phase of the program plan is the incorporation of the field data collected at the Piceance Basin to design monitoring schemes which embody information on:

1. site specific characteristics of lease tracts,
2. observed variances in animal abundance,
3. limited time and effort available for conducting monitoring studies,
4. and the quantitative objectives of a monitoring program.

Hence the Fall 1981 research results are presented in the context of the objectives for conducting small mammal or avifauna monitoring and the potential monitoring designs available for quantitative impact assessment.

MONITORING OBJECTIVES

Censusing small mammal and avifauna populations is currently standard practice in monitoring programs at oil shale lease tracts administered by the U. S. Geological Survey. One apparent reason for monitoring faunal abundance is to establish baseline levels for eventual mitigation of any identified losses which result from physical disturbance at the lease tracts. In the case of open pit mining, such losses are both predictable and unavoidable.

The purpose of PNL's research on faunal monitoring is to assess the potential of small mammal and avifauna populations as biomonitors of various components of the terrestrial ecosystem. In this regard, monitoring schemes which are capable of detecting off-site impacts of oil shale development at federal lease tracts are of concern. Significant changes in small mammal or avifauna populations at off-tract locations which can be quantitatively associated with oil shale development, would implicate possible water or airborne effluents. We consider small mammals and, to an extent, breeding bird populations as promising biomonitors because:

1. the species can provide localized fate and effects assessments due to relatively small home range sizes,
2. large data bases exist on the ecology and physiology of the species (i.e., deer mouse (*Peromyscus maniculatus*),
3. the species represent an important prey base,

4. permits can be readily obtained to collect small mammal specimens for chemical analysis (fate),
5. costs of field studies are much less than for large vertebrates (i.e., raptors, mule deer (*Odocoileus hemionus*)).

Because animal abundance is an expression of both natural and man-induced abiotic and biotic factors, assessments at the population level seem appropriate. For this reason, we have emphasized developing monitoring schemes to detect changes in abundance as an aid in the identification of ecologically important impacts. Changes in small mammal populations would signal the need for intensified environmental monitoring to identify causative agents based on the knowledge that biologically or physiologically significant effects have occurred. In contrast, the detection of increased levels of heavy metals, fluorides or organic compounds may in themselves be insufficient evidence to warrant intensified and costly environmental monitoring. Moreover, evidence from elevated tissue contaminant levels without associated data on ecological effects may be of limited value in assessing the need for possible changes in emission control technology.

At least four major steps can be identified in the ecological assessment of an energy technology. First, a qualitative evaluation or description of what is known about the environment and the technology is used to forecast potential environmental effects. The second step, both prior to and after a technology is initiated, is to monitor for ecological changes based on the forecasts and concerns identified in step one. At the third step, quantitative analysis of the monitoring data is conducted. If the assessment steps are properly integrated, the field study designs are specifically structured to detect and evaluate the impacts tested for in step three. The statistical and biological inferences derived from step three (for mitigation, deciding on additional monitoring, and feedback to step one) comprises the fourth step in an assessment.

Because of the current state-of-the-art in ecological assessment, only descriptive data on population dynamics are typically collected using traditional fish and wildlife census techniques. Such data are usually not relevant for quantitative evaluation of impacts (step three above). The monitoring schemes developed by the PNL research will be designed to detect impacts of a predetermined size (Δ) with a known certainty ($1-\beta$). Based on these criteria, the reliability of using small mammals and avifauna as biomonitors is being evaluated and their usefulness in quantitative impact assessments determined.

AN INITIAL MONITORING DESIGN

The interrelationship between the research goals of Phases I and II required that the Fall 1981 field study be conducted in conjunction with a design useful for monitoring programs. The principle requirement of an assessment design is that it must differentiate among changes in faunal abundance due to natural fluctuations and changes that result from impacts. Thus monitoring designs must be carefully structured and devised specifically for testing impact hypotheses in order to establish cause and effect relationships. Monitoring point-sources restricts the direct application of the traditional textbook experimental designs, when the objective is to quantify impacts. These restrictions include:

1. no randomization of treatments or controls to the landscape,
2. usually a single treatment area (the area influenced by the source) and only one to a few control areas are available.
3. replication of treatments are not possible or prohibitively expensive,
4. synchrony of regional populations resulting in autocorrelated and dependent observations.

Some currently advocated monitoring methods (Green 1979) do not account for these design limitations.

While no proposed assessment design eliminates all the statistical limitations associated with point-source monitoring, control-treatment pairing (CTP) designs have several advantages over more traditional approaches (Eberhardt 1976, 1978; McKenzie et al. 1977; Skalski and McKenzie 1982). Because of the advantages of CTP design, the Fall 1981 research program was conducted with its use in mind. The purpose of this section is to briefly discuss the basis of CTP designs and their advantages. The review of CTP designs is taken, in part, from a manuscript submitted for publication (Skalski and McKenzie, 1982).

The basic advantage of CTP designs is the use of spatial controls to account for temporal effects on dynamic systems (i.e., faunal communities). In a CTP design, potentially impacted (treatment) stations are paired with non-impacted (control) stations. The treatment stations are located within potential impact zones resulting from either airborne or waterborne effluents while the control sites are positioned outside the zones. As in classical experimental designs, the control areas are used to measure the effects of ambient conditions while the potential impact zones measure the same environmental conditions plus the effects of the hypothesized additional stimulus, (the impact).

In CTP designs, the control-treatment pairs are established during pre-operational monitoring and these station pairs are sampled into the operational period. Pre-operational sampling serves two functions. First, pre-operational sampling can be used to evaluate the success of the pairing scheme prior to the operational monitoring. More importantly, pre-operational sampling establishes the relationship between faunal abundance at control and treatment stations, (e.g. proportional abundance) which will be compared later with that observed during the operational period. With this ecological assessment scheme, an impact is defined as a statistically significant change in the proportional abundance of fauna at

control and treatment stations between pre-operational and operational periods (Chapman 1951; Eberhardt 1976).

A pivotal assumption in the successful use of CTP designs is that faunal abundance at control and treatment stations "track" each other, i.e., maintain a constant proportionality. This tracking assures that populations at the control and treatment stations respond similarly to changes in environmental conditions. Unless this assumption is valid, there is no statistical way to determine if changes in abundance at the treatment stations during the operational period are the result of temporal variability or an impact. The detection of differences in faunal abundance between control and treatment stations or between the pre-operational and operational populations is insufficient evidence alone for assigning causation of population changes to a point source (i.e., oil shale development). Both spatial and temporal controls are necessary to establish cause and effect relationships for observed changes in faunal abundance.

With proper station pairing, the use of proportional abundance also can account for annual and seasonal changes in abundance. Removal of annual variation allows repeated observations of a treatment combination between consecutive years to be designated as replicates. Thus, each year of the pre-operational or operational phase of the monitoring program is considered as one replicate in the analysis of CTP designs. It is this variation in proportional abundance between years which is used in testing the existence of ecological impacts. This removal of annual and seasonal changes in abundance also reduces the serial correlation among successive observations of faunal abundance. Serial correlation has been shown to seriously hamper analysis of variance procedures (Scheffé 1959). However, unpaired monitoring designs cannot generate true replicate observations because of the inherent spatial and temporal heterogeneity of terrestrial systems. Replicate observations are generally assumed to be samples from a single population with constant mean and variance.

When good control-treatment pairing is achieved, the variance of the difference in densities between the control and treatment stations should be reduced. The variance of the difference between two random variables, X_1 and X_2 , can be expressed as

$$\text{Var}(X_1 - X_2) = \text{Var}(X_1) + \text{Var}(X_2) - 2 \text{Cov}(X_1, X_2) .$$

With favorable pairing, the covariance in abundance between control and treatment stations should be positive, thus decreasing the observed variance and resulting in increased power for testing impact hypotheses. The decreased variance can also be used to reduce the levels of monitoring effort needed to detect impacts of specified size. McKenzie et al. (1977) compared the analyses of nuclear power plant monitoring data on zooplankton using both CTP designs and comparable unpaired experimental designs. He found up to a seven-fold reduction in the experimental error (MSE) associated with the use of CTP designs.

In summary, CTP designs have four distinct advantages over traditional unpaired designs frequently used in monitoring studies. These advantages are the following:

1. ability to relate changes in faunal abundance to oil shale development,
2. allows repeated observations of a control-treatment combination between years to be designated as replicates,
3. reduces or eliminates serial correlations among repeated observations on faunal abundance,
4. reduces the experimental error associated with the monitoring study.

Because of these advantages and indications from other data collected at Piceance Basin of synchrony of populations, sites selected for small mammal and avifauna censuses were based on criteria used in CTP designs.

FALL 1981 RESEARCH OBJECTIVES

The purpose of the Fall 1981 research was to begin the collection of field data necessary to provide guidance in designing monitoring schemes at the federal oil shale lease tracts. The objectives of the fall censuses were to evaluate alternative census techniques, test assumptions vital to the use of indices and abundance estimators, determine cost-functions associated with monitoring effects, and estimate variance components needed to devise optimal monitoring designs. Specific objectives of the fall research were as follows:

1. to estimate abundance of small mammals on replicate plots and the associated variance estimates using:
  - a. Lincoln Index (Seber 1973, pp. 59-60);
  - b. Removal sampling methods (Zippin 1956, 1958);
  - c. Mark-removal method (Skalski and Robson 1982, in press),
2. to test the validity of the mark-recapture, removal and mark-removal abundance estimates by means of statistical tests of goodness-of-fit, and tests of homogeneity presented in Skalski and Robson (1982, in press),
3. to test an assumption crucial in using catch indices for small mammal populations, that of homogeneity of capture probabilities among animals of the different replicate populations, by means of tests presented in Skalski and Robson, 1979, and Skalski, et al. 1982 (submitted),

4. to estimate avifauna abundance and the associated sampling variance using line-transect methods and Fourier series analyses (Burnham et al. 1980),
5. to determine if avifauna detectibility changes daily, diurnally or with habitat differences using analysis of variance and Fourier series procedures, (Results will indicate whether count indices or absolute abundance estimators are needed in monitoring avifauna populations at Piceance Basin.)
6. to estimate the plot-to-plot variance component associated with the faunal censuses,
7. to formulate cost functions associated with faunal censusing in multiple-plot studies.

STUDY SITES

Sites were selected for the Fall 1981 research with two objectives, 1) estimation of the plot-to-plot variance in animal abundance and 2) illustration and testing of the application of CTP designs at federal lease tracts. Six sites in the vicinity of Federal Lease Tract C-a were selected for these purposes. The six sites were paired between three gulches within constraints of the topography such that two sites were north of Tract C-a, two sites were south of C-a and two sites were directly downwind of the C-a tract. Within each pair of sites, one site was located in the near vicinity of Tract C-a while the other site was located 5 km or more further downwind of the tract (Figure 1).

In the context of CTP designs, the pair of sites in Corral Gulch-Yellow Creek Gulch (C1 and C2) represent areas along a potential treatment or impact gradient (Table 1). The sites in Ryan Gulch (R1 and R2) were selected because they represent areas along a southern control or non-impacted gradient. Similarly, the pair of sites in Duck Creek-Yellow Creek Gulch (D1 and D2) represent areas along a northern control gradient. Each pair of sites would be used in a CTP design to estimate proportional abundance during pre-operational and operational phases of the oil shale development of Tract C-a. The proportional abundance computed by sites C1 and C2 would be expected to change if site C1 was impacted by plant operations and this change would be detected relative to the proportional abundance computed by R1 and R2 to the south and D1 and D2 to the north of Tract C-a.

A properly implemented monitoring design consists of replicate study plots in both control/non-impacted and treatment/impacted areas and this was the basis for the Fall 1981 site selection. However, criteria used in selection are dependent upon the objectives of the field study. A distinction needs to be made between the objectives of estimation and hypothesis testing. If the objective was solely to estimate mean faunal

FIGURE 1. Map of Tract C-a Showing Study Site Locations for the Fall 1981 Small Mammal and Avifauna Censuses

TABLE 1. Location and Functional Description of the
Six Sites Used for Small Mammal and Avifauna
Censuses near Tract C-a

<u>Code Designation</u>	<u>Location</u>	<u>Functional Description in a CTP Design</u>
C1	T.1S., R.99W., Section 34	Treatment site along a potential impact gradient
C2	T.1S., R.98W., Section 21	Control site along a potential impact gradient
D1	T.1S., R.99W., Section 12	Treatment site along a control gradient
D2	T.1S., R.98W., Section 25	Control site along a control gradient
R1	T.2S., R.98W., Section 27	Treatment site along a control gradient
R2	T.2S., R.98W., Section 12	Control site along a control gradient

abundance in Piceance Basin, a form of random sampling or stratified random sampling would have been acceptable. In impact assessment, the objective is testing the hypothesis of no impact. Hence, a more restrictive set of criteria were used in the selection of sites for the Fall 1981 research.

With the purpose of hypothesis testing, replicate plots were selected purposely for their similarity. These similar or "replicate" plots were, in addition, selected for their location relative to potential control and impact areas. A single habitat type in a single terrain was selected for the sites because the more similar these replicate plots, the smaller the plot-to-plot variance in animal abundance should be, and the greater the likelihood impacts will be detected. The six replicate sites were located in sagebrush-greasewood (*Artemisia tridentata* - *Sarcobatus vermiculatus*) communities and all in gulch environments.

The sagebrush-greasewood community represents just one of several repetitive habitat types that could have been selected. The gulch environment was chosen as the location of the sites for several reasons, these include:

- location of the cold air drainage and water seepage from the lease tracts and so resulting in areas of potential impact,
- habitats with high small mammal abundance,
- repetitive feature of the landscape,
- individually isolated by topography,
- habitats least likely to be physically disturbed by development,
- orientation of development with gulch locations,
- accessibility.

While the six sites used during Fall 1981 illustrate some of the principles of CTP designs, they do not necessarily constitute a complete assessment design. One of the objectives of Phase II research is to determine the level of field replication needed to detect with assurance, $(1-\beta)$, reasonable changes in population abundance (Δ) the result of oil shale development.

METHODS

SMALL MAMMAL CENSUSES

Six 1-ha plots for censusing small mammal abundance were established in the vicinity of Tract C-a at sites C1, C2, D1, D2, R1, and R2 (Figure 1). All six plots were established in similar sagebrush-greasewood communities and located near the middle of the gulches. Traps were set 10 m apart in a 10 x 10 grid on each plot with trapping conducted simultaneously at all six areas. Trapping was conducted for five consecutive days (19-23 Oct 81) with two days of live trapping for marking the animals followed by three days of removal trapping. All trapping was conducted using Sherman live traps. Small mammals captured during the marking period were dye marked and released at respective points of capture. Species and sex were recorded for all animals captured.

Results of the mark-recapture study were summarized in a general data matrix (Skalski and Robson 1982) for each of the six plots and by species (deer mice (*Peromyscus maniculatus*), least chipmunk (*Eutamias minimus*)). Data from the matrices (Table 2) were used to estimate small mammal abundance by means of mark-recapture (Seber 1973, pp. 59-69), removal sampling methods (Zippin 1956, 1958) and the mark-removal method (Skalski and Robson 1982, in press). The validity of the absolute abundance procedures were tested by means of statistical tests of goodness-of-fit, and tests of homogeneity presented in Skalski and Robson (1979) and Skalski and Robson (1982, in press).

The homogeneity of capture probabilities among animals of the six different replicate populations was tested using both mark-recapture (Skalski et al. 1982, submitted) and removal sampling data (Skalski and Robson 1979). Results of the tests of homogeneity were used to determine whether simple catch indices rather than absolute abundance methods may be most appropriate for comparing small mammal abundance at Piceance Basin.

TABLE 2. General Data Matrix Including the Sample Sizes, n_i , Numbers Marked, x_{im} , and Numbers Unmarked, x_{iu} , During Marking ($i=1', 2'$) and Removal ($i=1, \dots, 3$) Phases and Associated Summary Statistics for the Small Mammal Censuses

Phase	Trapping Period	Number Marked (x_{im})	Number Unmarked (x_{iu})	Totals
Marking	1	$x_{1'm} = 0$	$x_{1'u}$	$M = x_{1'u} + x_{2'u}$
	2	$x_{2'm}$	$x_{2'u}$	
Removal	1	x_{1m}	x_{1u}	$n_1 = x_{1m} + x_{1u}$
	2	x_{2m}	x_{2u}	$n_2 = x_{2m} + x_{2u}$
	3	x_{3m}	x_{3u}	$n_3 = x_{3m} + x_{3u}$
Totals		$m = \sum_{i=1}^3 x_{im}$	$u = \sum_{i=1}^3 x_{iu}$	$r = \sum_{i=1}^3 n_i$ $t_2 = \sum_{i=1}^3 (i-1)n_i$

AVIFAUNA CENSUSES

Four 1.5-km line transects for use in avifauna censusing were established in the vicinity of Tract C-a at sites D1, D2, R1 and R2 (Figure 1). A Latin-square design was used in scheduling of the avifauna surveys. Surveys were conducted on 16, 17, 18 and 20 Oct 81 with each transect surveyed during one of four sampling periods on each day. The daily sampling periods corresponded to the times 8:00-9:15 a.m., 9:45-11:15 a.m., 11:45 a.m.-1:15 p.m. and 1:45-3:00 p.m. with each survey requiring 1-1.25

hr to complete. A total of 16 avifauna censuses were conducted. Species, sighting distance and sighting angle were recorded for each bird observed during the study.

Analysis of variance (ANOVA) procedures for Latin-square designs were used in the analysis of the avifauna survey data. Total bird counts and counts of dark-eyed junco (*Junco hyemalis*) were analyzed to test for effects of time of day, daily differences and plot-to-plot differences in bird counts. The Latin-square design provided six degrees of freedom to estimate the variance in bird counts.

Using the individual observations on sighting distance and angle, the sighting data were converted to perpendicular distances and log-transformed. Analysis of variance procedures tested whether the mean perpendicular sight distance was effected by the time of day the survey was conducted, daily differences and plot-to-plot differences. The ANOVA procedures served as tests of homogeneous detectibility and were used to determine whether indices such as bird counts or absolute abundance procedures (Burnham et al. 1980) were necessary in monitoring fall avifauna abundance.

RESULTS

SMALL MAMMAL CENSUSES

During the 3000 trap-nights of effort used to conduct the Fall 1981 censuses, 383 small mammals were captured on the six study plots in sagebrush-greasewood communities (Table 3). Deer mice (*Peromyscus maniculatus*) constituted 70.0% of the catch and least chipmunks (*Eutamias minimus*) 28.5% of the small mammals trapped.

Tests of Homogeneous Capture Probabilities

When the purpose of conducting animal censuses is for the quantitative comparison of populations, absolute abundance procedures are no longer used to estimate animal numbers, but rather to estimate capture probabilities (Skalski et al. 1982, submitted). When the probabilities can be assumed equal, comparative techniques based on population indices (the number of distinct animals trapped) have been shown to be up to 20 times more efficient as comparable methods based on abundance estimates (Skalski et al. 1982, submitted). Tests of homogeneity based on capture data can be used to determine whether these capture probabilities are equal among populations being compared. If the capture rates are found to be unequal, estimates of the probabilities can be used to adjust the indices to still provide valid statistical comparisons of abundance. Catch data from Piceance Basin were used to test whether the simpler and more efficient indices of abundance could be used in assessment programs at the lease tracts.

Both the mark-recapture and removal sampling data (Appendix A) were used to test for homogeneous capture probabilities among small mammals of the six replicate plots. The purpose of the tests was to determine whether capture probabilities were similar in populations censused simultaneously to eliminate potential temporal effects on catchability. Catch rates of

TABLE 3. Numbers of Distinct Individuals Captured of Different Species at the Six Small Mammal Plots 19-23 Oct 81

Species	C1	C2	D1	D2	R1	R2	Species Total
<i>Peromyscus maniculatus</i>	53	76	48	35	34	22	268
<i>Eutamias minimus</i>	11	4	29	18	18	29	109
<i>Mustela erminea</i>	1	0	0	1	0	0	2
<i>Mustela frenata</i>	1	0	0	0	0	0	1
<i>Microtus montanus</i>	0	1	0	0	0	0	1
<i>Reithrodontomys megalotis</i>	0	1	0	0	0	0	1
<i>Perognathus spp.</i>	0	0	1	0	0	0	1
Plot Total	66	82	78	54	52	51	383

gray squirrels (*Sciurus carolinensis*) have been shown to be affected by habitat differences (Perry et al. 1977). Weather factors (Getz 1961, Mystkowska and Sidorowicz 1951, Gentry et al. 1966) and seasonal changes (Klonglan 1955, Perry et al. 1977) also have been shown to influence capture rates.

Using the vectors of catch data (M-m, m, u) from each small mammal plot, a chi-square test of homogeneity was constructed using a 3 x 6 contingency table with ten degrees of freedom (d.f.) (Skalski et al. 1982, submitted) for the *P. maniculatus* and *E. minimus* data. The tests of homogeneity were used to determine whether the capture probabilities during the 2-day marking and the 3-day removal sampling periods were equal for the six populations compared. The null hypothesis of homogeneity was rejected

TABLE 4. Results of Tests of Homogeneous Capture Probabilities Using Mark-Recapture and Removal Sampling Data for *P. maniculatus* and *E. minimus*

Species	Mark-Recapture Sampling		Removal Sampling	
	Test Statistic (χ^2_{10})	α -Level	Test Statistic (χ^2_5)	α -Level
<i>P. maniculatus</i>	20.26	0.027	2.29	0.808
<i>E. minimus</i>	16.22	0.093	4.04	0.544

for the *P. maniculatus* data ($\alpha < 0.05$) but was not rejected for the *E. minimus* data ($0.10 < \alpha < 0.05$) (Table 4).

Similarly, using the vectors of removal data (n_1, n_2, n_3) from the six plots, tests of homogeneity were constructed using the Q-statistic (Skalski and Robson 1979) distributed as a chi-square with 5 d.f. The tests were used to determine whether capture probabilities during the 3-day removal period alone were equal for the six populations. Hypotheses of homogeneity were not rejected ($\alpha > 0.05$) for either the *P. maniculatus* or *E. minimus* data (Table 4).

The homogeneity in capture probabilities during the 3-day removal period suggests differences in catchability may only have existed during the marking period. The trap mortality which occurred (Appendix A) during marking may be a consequence of stresses also experienced by the *P. maniculatus* which were marked and released back into the populations. If such stresses existed, the effects of marking and handling the animals may have resulted in unequal and differential catchability in the replicate populations. Therefore, the observed heterogeneity may be an artifact of handling practices and not inherent differences in the catchability of small mammals between plots. Additional tests scheduled for spring and summer 1982 sampling periods will add information about the existence of

spatial effects on catchability of small mammals. At present the possibility exists that indices may be valid means of population comparison of small mammals at federal lease tracts.

Abundance Estimates and Their Validity

A rational choice on which census procedure to use in a study such as at Piceance Basin is difficult because the validity of a proposed abundance estimator can only be determined *a posteriori*, if determined at all. Therefore, a census procedure was chosen for the Fall 1981 field research which yields capture data conformable to a number of models. It was hoped that by the incorporation of a number of techniques, at least one might provide valid estimates of small mammal abundance. An additional constraint in the selection of possible methods was to find a field procedure which was efficient enough to provide precise abundance estimates with reasonable levels of effort.

In impact assessment studies, multiple plots will be necessary and the populations on those plots censused to validly test the hypotheses of no impact. Eberhardt (1978) states that as in the case of classical designs, it is the plot-to-plot variance which must be estimated and used to test impact hypotheses. The necessity for replicate plots across the landscape precludes the practice of intense characterization of the population dynamics on just a few representative plots. Field methods must focus on census techniques which can estimate abundance with minimal effort and yet be robust to changing requirements imposed on the estimators the result of fluctuating environmental conditions.

The mark-removal method (Skalski and Robson 1982, in press) was chosen for the Fall 1981 small mammal censuses because of its flexibility and because abundance estimates can be obtained in relatively short periods of time, say a 5-day trapping session. The multiple mark-recapture methods of

Otis et al. (1978) also provide for flexible data analysis but the procedure was considered to be too labor intensive for routine monitoring studies as are being investigated at Piceance Basin.

The choice of the proper abundance estimator using the data from the mark-removal field procedure (Appendix A) depends on the validity of two assumptions. These assumptions are:

1. Marked and unmarked animals have equal probabilities of capture during the 3-day removal sampling phase of the census.
2. The probability of capture is constant during the three days of removal sampling (i.e., goodness-of-fit to a geometric removal model).

Depending on the validity of the above assumptions, small mammal abundance on a plot can be estimated using mark-recapture, removal sampling, or mark-removal estimators (Skalski and Robson 1982, in press). The statistical tests of these assumptions are presented in Skalski and Robson (1979, 1982, in press).

The homogeneity of capture probabilities during the removal period permitted the catch data (Appendix A) to be pooled from the six plots for testing goodness-of-fit to the removal model. Goodness-of-fit was then tested by two means. The total catch (marked and unmarked animals) and the captures from unmarked animals were tested by statistics for goodness-of-fit to a geometric model for removal sampling developed by Skalski and Robson (1979) and presented later in Skalski and Robson (1982, in press) (Table 5). Exploiting the fact that the population abundance of marked animals is known at the onset of removal sampling, an alternative goodness-of-fit test (Skalski and Robson 1982, in press) for just the marked population was performed (Table 5). This later test has less power but is sensitive to a wider variety of violations of assumptions, including

TABLE 5. Results of Tests of Goodness-of-Fit to the Geometric Removal Model and Tests of Equal Catchability for Marked and Unmarked *P. maniculatus* and *E. minimus**

Tests of Assumptions	<i>P. maniculatus</i>		<i>E. minimus</i>	
	Test Statistic	α -Level	Test Statistic	α -Level
1. Goodness-of-fit to geometric removal model				
Total catch	$Z = 0.274$	$P(Z > 0.274) = 0.392$	$Z = 0.147$	$P(Z > 0.147) = 0.442$
Unmarked animals only	$Z = 0.425$	$P(Z > 0.425) = 0.335$	$Z = -0.161$	$P(Z > -0.161) = 0.564$
2. Goodness-of-fit				
Marked animals only	$Z = -1.523$	$P(Z < -1.523) = 0.064$	$Z = -1.315$	$P(Z < -1.315) = 0.094$
3. Equal catchability of marked and unmarked animals in removal phase				
Total catch	$\chi^2_1 = 31.828$	$P(\chi^2_1 > 31.828) = 0.000$	$\chi^2_1 = 13.210$	$P(\chi^2_1 > 13.210) = 0.000$

*Tests based on the catch data pooled from the six replicate plots.

lack of closure. Results of these goodness-of-fit tests suggest that while the unmarked populations may well fit the removal model, marked *P. maniculatus* and *E. minimus* may not ($0.10 > \alpha > 0.05$).

A test of the assumption of equal catchability of marked and unmarked animals during the removal sampling is exactly equivalent, in type, to the tests of homogeneity performed earlier to determine whether capture probabilities were equivalent between populations during the removal sampling. The tests of homogeneity (Table 5) indicated significant heterogeneity in capture probabilities between marked and unmarked animals in populations of *P. maniculatus* and *E. minimus*. Consequently, mark-recapture type estimators were not considered to be valid means of estimating abundance using the small mammal data from the Fall 1981 censuses.

Interpretation of the tests of assumptions suggest that while the removal samples for the unmarked segments of the six populations censused are homogeneous and conform to a geometric removal model, capture probabilities for marked animals differ from the unmarked individuals and do not conform to that expected under a geometric removal model. These results are consistent with what might be expected if marking had an effect on the small mammals which were handled, changing their behavior and trap response. With this configuration of census results, small mammal abundance was estimated by adding to the marked populations, estimates of the unmarked animals remaining in each population computed by means of the removal estimator (Zippin 1956, 1958).

The abundance estimates for small mammals on each plot were computed according to the formula:

$$\hat{N}_i = M_i + \frac{u_i}{(1 - \hat{q}^3)} \quad \text{for } i = 1, \dots, 6$$

where $\hat{N}_i$ = estimate of abundance on the i th plot, $i=1, \dots, 6$

M_i' = number of animals marked (M) plus handling mortalities on the i th plot, $i=1, \dots, 6$

u_i = number of unmarked animals captured during the three days of removal sampling on the i th plot, $i=1, \dots, 6$

$\hat{q} = (1 - \hat{p})$ = pooled estimate of the daily probability of escaping capture for unmarked animals on the six plots.

The estimate $\hat{p}$ was computed according to the formula

$$\hat{p} = \frac{5u_{\cdot} - 3t_{2\cdot} - \left(u_{\cdot}^2 + 6u_{\cdot}t_{2\cdot} - 3t_{2\cdot}^2\right)^{1/2}}{(4u_{\cdot} - 2t_{2\cdot})}$$

and where $u_{\cdot} = \sum_{i=1}^6 u_i = \sum_{i=1}^6 \sum_{j=1}^3 x_{iju}$

$$t_{2\cdot} = \sum_{i=1}^6 \sum_{j=2}^3 (j-1)x_{iju}$$

are summary statistics for the removal sampling data for unmarked animals summed over the six replicate plots. Daily capture probabilities for *P. maniculatus* and *E. minimus* were estimated at 0.390 and 0.608, respectively.

Mean abundance for *P. maniculatus* per plot (1 ha) was estimated at 50.5 animals, with a range in abundance of 25.2 - 84.5 (Table 6). Mean abundance of *E. minimus* was less in these sagebrush-greasewood communities with an average of 19.1 animals, and a range in numbers of 4.2 - 31.9 (Table 7). The coefficients of variation for abundance between replicate

TABLE 6. Estimates of *P. maniculatus* Abundance on the Six 1-ha Plots in Sagebrush-Greasewood Communities in the Vicinity of Tract C-a

	Small Mammal Plots					
	C1	C2	D1	D2	R1	R2
Numbers captured during marking period (M')	30	47	23	21	16	11
Estimated unmarked	29.8	37.5	32.3	18.1	23.3	14.2
Estimated abundance ($\hat{N}$)	59.8	84.5	55.3	39.1	39.3	25.2

TABLE 7. Estimates of *E. minimus* Abundance on the Six 1-ha Plots in Sagebrush-Greasewood Communities in the Vicinity of Tract C-a

	Small Mammal Plots					
	C1	C2	D1	D2	R1	R2
Numbers captured during marking period (M')	6	1	17	12	5	17
Estimated unmarked	5.3	3.2	12.8	6.4	13.8	14.9
Estimated abundance ($\hat{N}$)	11.3	4.2	29.8	18.4	18.8	31.9

plots for *P. maniculatus* and *E. minimus* were 41.1% and 55.5% respectively. Illustrations of the statistical analyses of the small mammal data are presented in Appendix B.

Estimation of Variance Components

A primary purpose in Phase II research is to determine the levels of field effort required to detect impacts of reasonable size (Δ) on populations of small mammals and avifauna. Monitoring efforts to detect such changes will be determined in terms of the numbers of replicate study plots needed for an assessment and the levels of effort required to precisely census faunal abundance on each replicate plot. To provide for optimal allocation of efforts between and within plots, estimates of the sampling error and plot-to-plot variance in faunal abundance in the vicinity of a lease tract will be necessary. Using the fall census data, initial estimates can be computed. Additional sampling planned for spring and summer 1982 will help determine whether such estimates are seasonally dependent.

Based on findings that the capture probabilities were homogeneous across plots during the three days of removal sampling and that the data fit sufficiently well to the removal model, variance components were estimated based on the removal data. The removal data from the marked animals were included in these calculations because for the purpose of variance estimation, the high overall removal rates should sufficiently dampen any heterogeneity that may exist between individuals in a population and permit reliable estimation (Seber and White 1970).

Let r_i define the number of distinct animals captured on plot i during the three day removal sampling period and N_i the animal abundance on plot i . Then we can write the identity

$$r_i = E(r_i) + [E(r_i | N_i) - E(r_i)] + [r_i - E(r_i | N_i)]$$

and taking expected values

$$r_i = \mu p' + (N_i p' - \mu p') + (r_i - N_i p'). \quad (1)$$

Expression (1) describes the catch at plot i by a linear model composed of a mean catch of $\mu p'$ plus deviations attributable to between-plot differences in abundance ($N_i p' - \mu p'$) and sampling error ($r_i - N_i p'$). Taking the variance of (1), the variance of r_i is found to be

$$\text{Var}(r_i) = p'^2 \sigma_N^2 + \mu p' q' \quad (2)$$

where σ_N^2 = variance in animal abundance N_i between plots,
and p' = three-day capture probability = $(1-q^3)$.

Expression (2) forms the basis for the estimation of variance components.

Using the removal data from the six plots and pooling the observations ($n_1 = 120$, $n_2 = 46$, $n_3 = 21$) estimates of the mean abundance (μ) and the capture probability ($1-q^3$) were computed (Zippin 1956, 1958) for *P. maniculatus*. The pooled data estimated $\hat{\mu} = 33.44$ and $\hat{p}' = 0.9321$. By equating (2) to the observed sampling variance of r_i for the six plots and using the pooled estimates $\hat{\mu}$ and $\hat{p}'$, the plot-to-plot variance was found to be 214.61. The expression $\mu p q$ then estimates the sampling error at 2.12 during the three days of removal sampling for the censuses of *P. maniculatus*.

In a similar manner, variance components were estimated based on the pooled removal data ($n_1 = 80$, $n_2 = 17$, $n_3 = 5$) from the censuses of *E. minimus*. The pooled data estimated $\hat{\mu} = 17.22$ and $\hat{p}' = 0.987$. Consequently, the plot-to-plot variance in *E. minimus* was estimated at 85.93 and the sampling error associated with the removal sampling during the Fall 1981 censuses was 0.21.

These results indicate that animal abundance on the individual plots were estimated with high precision during Fall 1981. Further, the coefficients of variation for the abundance of *P. maniculatus* and *E. minimus* (41.1% and 55.5%, respectively) are almost totally the result of actual differences in abundance between plots, say the plot-to-plot variance. There was a 100-fold difference in the size of the variance components for the between and within plot errors.

The estimates of the variance components strongly suggest that "extensive" rather than "intensive" sampling schemes should be used in the monitoring of the small mammal populations. In other words, numerous replicate plots placed across the landscape will be necessary to account for the relatively large size of the plot-to-plot variance and these populations need to be sampled only superficially. Such a scheme puts the monitoring efforts where the variances are the greatest and where the returns in improved precision are the most likely. Suggestions on exact allocations for effort between and within plots will be part of future work on this continuing project. Additional sampling and data reviews will be used to establish whether the high capture probabilities ($p' > 0.90$) are typical or are seasonally dependent. Changes in capture probabilities with changing seasons may require alternative allocation schemes.

Cost Function for the Censuses

Besides estimates of the variance in small mammal abundance, cost functions for multi-plot surveys are necessary to optimally allocate monitoring efforts. A cost function expresses in monetary terms the costs of data collection based on the numbers of replicate plots and the trapping effort per plot. During Fall 1981 the expenditures of time spent on locating the study sites, site preparation and trapping efforts were recorded to construct realistic formulations describing field costs.

As a working premise, the basic unit of effort was considered to be a 2-person hour. In other words, one hour of labor spent by a 2-person field crew. Hence, subsequent calculations are based on the efficiency of 2-person field teams, and probably cannot be extrapolated or be considered equivalent to one person working for two hours. Locating the six small mammal plots required 22 units of effort, site preparation 31 units and trapping small mammals 64.5 units of effort.

A potential cost function describing the small mammal field work can be expressed in terms of four components. These are:

1. Fixed costs associated with the initiation any study, independent of of size. These costs include travel to the area, orientation and equipment preparation.
2. Costs associated with the location of the study sites and which should be directly proportional to the number of plots chosen.
3. Costs associated with site preparation including equipment purchases and field layouts. These costs may be considered as a first approximation to be directly related to the size of the study plots.
4. Costs directly associated with conducting the faunal censuses and again as a first approximation may be considered to be directly related to the number of study plots.

The amount of fixed costs will depend on who is conducting the study. Such costs may differ if environmental consultants, universities or the oil companies themselves conduct the monitoring projects. Locating study sites required approximately 0.5 days of effort per site based on experience from Fall 1981. The costs of site preparation include equipment and field labor, and on a per trap basis, labor amounts to 0.0065 days/trap/plot. Using the mark-removal method as a possible census method or something equivalent, six days of trapping effort are necessary to conduct the

censuses. However, based on the Fall 1981 experiences, a 2-person team will be necessary for every four plots established.

Based on labor expenditures from the Fall 1981 field research, the following cost function was established:

$$\text{COSTS} = A + 0.5BX + (C + 0.0065B)XY + 6B \left[\frac{X}{4} \right]$$

where A = fixed costs,

B = cost of one day support, labor, and transportation for a 2-person field crew,

C = per trap cost plus any additional materials needed to mark its location,

X = number of plots,

Y = number of traps per plot,

and where $\left[\right]$ denotes the smallest integer that is greater than or equal to the expression.

AVIFAUNA CENSUSES

A total of 258 birds among 18 avifauna species were sighted during the course of the 16 line-transect surveys (Table 8). An average of 16.1 birds were sighted per survey using line-transects of length 1.5 km. The most commonly sighted species was the dark-eyed junco (*Junco hyemalis*) which accounted for 53.9% of the sightings and was observed on all but one survey. The next most commonly sighted species was the white-crowned sparrow (*Zonotrichia leucophrys*) which accounted for just 14.7% of the sightings and was observed on seven of the 16 surveys.

Tests of Homogeneous Detectability

In only one of the 16 surveys conducted were 40 or more birds sighted. Included among these sightings were both individual birds and flocks of

TABLE 8. Frequency of Occurrence of the 18 Bird Species Sighted During the Course of 16 Line-Transect Surveys

Common Name	Scientific Name	Total Count During Surveys	Percent of Count	Number of Surveys Where Observed
Dark-Eyed Junco	<i>Junco hyemalis</i>	139	53.9	15
White-Crowned Sparrow	<i>Zonotrichia leucophrys</i>	38	14.7	7
Horned Lark	<i>Eremophila alpestris</i>	30	11.6	3
Mountain Chickadee	<i>Parus gambeli</i>	14	5.4	6
Sage Sparrow	<i>Amphispiza belli</i>	7	2.7	5
Cassin's Finch	<i>Carpodacus cassinii</i>	6	2.3	1
Mountain Bluebird	<i>Sialia currucoides</i>	5	1.9	2
Clark's Nutcracker	<i>Nucifraga columbiana</i>	3	1.2	2
Song Sparrow	<i>Melospiza melodia</i>	2	0.8	1
Western Meadowlark	<i>Sturnella neglecta</i>	2	0.8	2
Scrub Jay	<i>Aphelocoma coerulescens</i>	2	0.8	2
Black-Billed Magpie	<i>Pica pica</i>	2	0.8	1
Loggerhead Shrike	<i>Lanius ludovicianus</i>	2	0.8	2
Sharp-Shinned Hawk	<i>Accipiter striatus</i>	2	0.8	2
Mourning Dove	<i>Zenaidura macroura</i>	1	0.4	1
Robin	<i>Turdus migratorius</i>	1	0.4	1
Hairy Woodpecker	<i>Dendrocopos villosus</i>	1	0.4	1
Pinyon Jay	<i>Gymnorhinus cyanocephalus</i>	1	0.4	1
Totals		258	100%	55

Individuals, a common occurrence during the fall migratory season. Burnham et al. (1978) recommends that at least 40 sightings of individual birds be used as the basis for estimates of a detection function using Fourier series analysis. The lack of sufficient sightings required other means of analyses be used to investigate detectability during the surveys.

Using analysis of variance techniques for a Latin-square design, the existence of temporal and spatial effects on mean detection distance were tested. Sighting distance and angle measurements were converted to perpendicular distances, then log-transformed before analysis. Sightings from flocks and extreme observations (≥ 200 m) were excluded to minimize problems of heteroschedasticity and lack of independence (Appendix C).

Results of the analyses of total sightings from all species (Table 9) and sightings of *J. hyemalis* (Table 10) indicate that the mean perpendicular sighting distance was not constant during all surveys. Significance of the lack-of-fit hypotheses suggests that the relationships between detection distance and the effects of daily differences, site differences and survey times are not simply additive. Further examination of mean perpendicular sighting distances for each survey indicate no consistent pattern in mean distances between the four sites or between survey times. Hence the changes in mean detection distance cannot be attributed to a single effect. The consequence is that the survey data cannot be pooled across censuses to increase sample sizes and permitting estimates of the detection function by means of Fourier analysis.

An additional consequence of the findings of significant differences in detection distances is that the bird counts cannot be strictly used in valid comparisons of avifauna abundance. To correctly interpret avifauna censuses, counts from the surveys would need to be adjusted for the probabilities of detection which uniquely existed during the time of the surveys. The extent of such adjustments and their effect on comparisons of avifauna abundance cannot be assessed, however, without their estimation. It appears line-transects considerably longer than 1.5 km would be

TABLE 9. Analysis of Variance Table for Log-Transformed Perpendicular Sighting Distances Based on Observations from All Avifauna Species

<u>Source</u>	<u>D.F.</u>	<u>M.S.</u>	<u>F</u>	<u>α</u>
Total (corrected)	206			
Between sites	3	2.716	3.247	0.023
Between days	3	2.538	3.034	0.031
Between survey times	3	2.184	2.611	0.053
Lack-of-fit	5	1.828	2.186	0.058
Error	192	0.837		

TABLE 10. Analysis of Variance Table for Log-Transformed Perpendicular Sighting Distances Based on Observations of *J. hyemalis*

<u>Source</u>	<u>D.F.</u>	<u>M.S.</u>	<u>F</u>	<u>α</u>
Total (corrected)	116			
Between sites	3	1.283	1.620	0.189
Between days	3	3.816	4.819	0.004
Between survey times	3	1.910	2.412	0.071
Lack-of-fit	5	2.544	3.212	0.010
Error	102	0.792		

necessary to assure sufficient observations to estimate avifauna abundance during the fall season by means of Fourier series analysis or other available methods.

Variability in Avifauna Abundance

The lack of sufficient bird sightings per survey prevented the estimation of bird densities and associated sampling errors of such estimates by means of Fourier series analysis (Burnham et al. 1978). Without density estimates and their variances, the between-site variance in avifauna abundance could not be properly computed.

However, using the Latin-square survey scheme, the variances associated with the bird counts (Table 11) from the 16 surveys were approximated. Scheffé (1959: p. 153) gives expressions for the expected values of the mean squares for an analysis of variance of a Latin square design and these expressions were used to estimate variance components. The mean number of birds sighted per survey was 16.1 individuals. Based on the results of the analysis of variance (Table 12), sampling error was estimated to be 18.08 and the variance in avifauna abundance between sites was estimated at 104.04. Hence a 5-fold difference in the sizes of the sampling error and the between-sites variance was observed. The F-test for the main effect of sites indicates that the variance between sites is indeed significantly different ($\alpha < 0.01$) from zero.

Using just the counts of *J. hyemalis* the most abundant species observed on the surveys, the mean number observed per survey was 8.7 with an estimated sampling error of 26.15 and an estimated between-site variance of 62.02. Again the between-site variance was found to be significantly different ($\alpha < 0.01$) from zero and was 2.4-fold larger than the sampling error (Table 13).

TABLE 11. Total Bird Counts and Numbers of *J. hyemalis* (in parentheses) Sighted During the 16 Line-Transect Surveys. Data are presented according to study sites (D1, D2, R1, R2), census periods during the day and date.

Date	Census Period			
	8:00 - 9:15 am	9:45 - 11:15 am	11:45 - 1:15 pm	1:45 - 3:00 pm
16 Oct 81	R1 - 16 (8)	R2 - 8 (1)	D1 - 37 (9)	D2 - 0 (0)
17 Oct 81	D1 - 48 (35)	D2 - 15 (5)	R1 - 23 (15)	R2 - 14 (7)
18 Oct 81	R2 - 14 (1)	D1 - 26 (24)	D2 - 9 (2)	R1 - 6 (5)
20 Oct 81	D2 - 10 (3)	R1 - 13 (11)	R2 - 6 (1)	D1 - 13 (12)

TABLE 12. Analysis of Variance Table for the Latin Square Design Used in the Analysis of Total Bird Counts

Source	D.F.	M.S.	E(M.S.)	$\hat{\sigma}^2$	F-Statistic	α -Level
Total (corrected)	15					
Between sites	3	418.25	$\sigma^2 + 4\sigma_s^2$	100.04	23.129	0.001
Between days	3	155.75	$\sigma^2 + 4\sigma_D^2$	34.42	8.613	0.014
Between survey times	3	138.42	$\sigma^2 + 4\sigma_T^2$	30.09	7.654	0.018
Error	6	18.08	σ^2	18.08		

TABLE 13. Analysis of Variance Table for the Latin Square Design Used in the Analysis of Sighting Counts of *J. hyemalis*

Source	D.F.	M.S.	E(M.S.)	$\hat{\sigma}^2$	F-Statistic	α -Level
Total (corrected)	15					
Between sites	3	274.23	$\sigma^2 + 4\sigma_s^2$	62.02	10.488	0.008
Between days	3	90.90	$\sigma^2 + 4\sigma_D^2$	16.19	3.476	0.091
Between survey times	3	30.40	$\sigma^2 + 4\sigma_T^2$	1.06	1.163	0.399
Error	6	26.15	σ^2	26.15		

The estimates of the variance components resulting from the analysis of variance tables were based on the assumption that the model for a Latin-square design was valid. When interactions exist, the estimates of variances are biased (Scheffe 1959:p. 154-158) and alternative expressions for the expected mean squares are appropriate (Scheffé 1959:p. 304-312). The fact that interactions were found significant ($0.10 > \alpha > 0.01$) in the analysis of mean detection distances may also imply that interactions may exist in the relationship between bird counts and the effects of differences between plots, days and times of surveys. However, possible interaction terms cannot be estimated from the current survey scheme, and consequently, any appropriate adjustments in variance estimates are not possible.

Review of the analysis of variance Tables 12 and 13, indicate significant ($\alpha < 0.05$) main effects also existed for between days and between survey times for total bird counts. Regardless of possible causes, temporal effects appear to significantly influence ($\alpha < 0.05$) bird counts and the use of blocking, as employed in the Latin-square design, can substantially reduce experimental error. When blocking for days and survey times are taken into account the mean square error (MSE) for total bird counts is computed to be 18.08 (Table 12), however, when the same data is analyzed ignoring the blocking the MSE is 82.53. In Phase II research of this project to develop monitoring designs, the properties of blocking will be used in the design of survey schemes.

Cost Function for the Surveys

The levels of effort used to locate and establish the avifauna transect-lines and to conduct the surveys were recorded during Fall 1981. These data formed the basis of a cost function describing the collection costs for the avifauna census data. Cost function was constructed based on four components, these were:

1. fixed costs,
2. costs of locating suitable avifauna survey sites,
3. costs of equipment and labor to establish the line-transects,
4. costs of conducting the avifauna surveys.

The function may be written as:

$$\text{COST} = A + 0.5BX + (C + 0.33B)XY + DB \left[\frac{XY}{6} \right]$$

where A = fixed costs of initiating an avifauna survey program,

B = cost of 1-days support, labor and transportation for a
2-person field crew.

C = equipment costs of marking 1-km of line transect.

D = number of days surveys are to be repeated,

x = number of avifauna survey sites established,

y = length of line-transects in km,

and where $\left[\right]$ denotes the smallest integer that is greater than or equal to the expression.

The cost function is based on several simplifying assumptions including that the establishment costs are directly proportional to line-transect length. Another major assumption is that labor costs for conducting the surveys is proportional to the total distance of line-transects established. One 2-person field crew is considered to be capable of conducting approximately 6-km of line-transect per day including necessary travel based on observations from the Fall 1981 field work. An additional 2-person crew is deemed necessary for every 6-km of line-transect established.

The additional sampling periods planned for spring and summer of 1982 will be used to refine and validate the cost function for avifauna surveys. As written, the equation is a step function, and to be used in future calculations to optimize allocation of monitoring efforts, an additional approximation using a continuous function will be needed. Continuous functions will be developed as part of Phase II research.

DISCUSSION

The small mammal census grids and the avifauna line-transects were all located in what may be considered as "equally suitable sites". The gulch terrains were selected for the location of the censuses because they represented areas of potential impact with future development of oil shale. The gulch terrains possessed many of the qualities deemed necessary to establish viable control and treatment areas for quantitative impact assessment.

An important quality in assessing the utility of small mammal and avifauna censuses was the extent of the natural variability in faunal abundance in gulch environments. The more homogeneous the environment, and the faunal populations residing in the habitats, the greater is the probability that impacts will be detected if they occur. For this reason, a single vegetation type was selected for the placement of all sites, the sagebrush-greasewood community. Study sites were selected as similar as possible with the hope that by purposely selecting such sites, the variability in faunal abundance would be minimized. Other forms of site selection, such as the random sampling of locations would have resulted in necessarily larger variances. In the context of experimental design or survey sampling theory, the sagebrush-greasewood community would be considered a "block" or "sampling strata" selected for the homogeneity of the elements within the category.

With sites selected for uniformity, the purpose of separately estimating the variance components for sampling error and plot-to-plot variance was to determine the relative contributions of observer error and environmental heterogeneity to the overall variance in field sampling. Estimation of the plot-to-plot variance in abundance also permitted an evaluation of the size of the variance in the response variable being monitored.

During Fall 1981, the mean abundance of *E. minimus* was estimated at 19.1 per 1-ha plot; however, the variance in abundance between plots was estimated at 85.93. Similarly, for *P. maniculatus* mean abundance was estimated at 50.5 individuals per 1-ha plot and with a plot-to-plot variance in abundance of 214.61. Both species are characterized by considerable heterogeneity in abundance. Examination of the bird count data from the line-transects show similar results. Mean count per survey was 16.1 birds but with a between site variance of 100.04. Sampling error in all these cases was considerably smaller than the between plot variance.

Two general conclusions can be made from these results. First, it appears that monitoring efforts should not be concentrated to a few plots where animal abundance is intensely characterized. The heterogeneity in abundance suggests monitoring efforts should be placed at the replicate plot level and not at sampling individual animals. The specific allocations of efforts to optimize monitoring efforts for finite resources is the subject of Phase II research on this project. Secondly, because of the large heterogeneity in abundance, use of a few representative plots allocated to the various habitat types present in the Piceance Basin may result in quite misleading conclusions. Even such simple aspects as the relationship between abundance or faunal composition and habitat type may be misconstrued if study plots are not replicated.

Among the four replicate avifauna line-transects (all within the same sagebrush-greasewood community), the proportion of bird counts attributable to the dark-eyed junco (*J. hyemalis*) differed significantly between transects ($\chi^2_3 = 33.286, \alpha < 0.01$). Similarly, the ratio of *P. maniculatus* to *E. minimus* on the six small mammal plots was estimated at $\hat{R} = 2.65$ but with a variance estimate of $\hat{\text{Var}}(\hat{R}) = 18.45$. The observed variance in the ratio of the two species was found too large with even a sample of six plots to permit precise estimates of the relative composition of the two species.

Statistical inferences as to differences in faunal abundance or species composition between habitat types, between control and impacted areas, or between periods of time requires replication at the population level. The variance estimates obtained during the Fall 1981 field sampling will provide the basis to determine the levels of replication needed to detect reasonable changes in abundance the possible result of impacts.

SUMMARY

Censuses were conducted during October 1981 to estimate the fall abundance of small mammals and avifauna on replicate plots in the vicinity of Federal Tract C-a (Rio Blanco Oil Shale Company). The objectives of the fall censuses were to evaluate alternative census techniques, test assumptions vital to the use of indices and abundance estimators, determine cost-functions associated with monitoring efforts, and estimate variance components needed to devise optimal monitoring designs. Analyses of the fall census data on small mammal abundance indicate:

- Coefficients of variation (CV) were 40-50% for estimates of small mammal abundance, suggesting that suitable monitoring designs are possible.
- Average deer mice abundance (*Peromyscus maniculatus*) on a 1-ha plot in sagebrush-greasewood communities was 50.5 animals. Plot-to-plot variance was 214.6, sampling error 2.1. This 100-fold difference in variance components strongly suggests "extensive" rather than "intensive" sampling will be appropriate in designing the assessment studies.
- The small sampling error resulted from 3-day capture rates in excess of 90%, suggesting seasonal patterns in catchability must be considered in allocating monitoring efforts.
- Capture probabilities were not significantly different ($\alpha > 0.10$) for replicate populations censused simultaneously during removal sampling, suggesting that indices of abundance rather than absolute abundance procedures may be appropriate with subsequent reductions in monitoring costs.

- The topography of the Piceance Basin seems suitable for using control-treatment pairing (CTP) designs for impact assessments; designs which have been demonstrated to reduce the size of monitoring programs.
- The mark-removal census procedure employed during the fall period appears to be consistent with the objectives of both fate and effects monitoring, since the census procedure provided both valid abundance estimates and specimens for chemical analysis.
- Chi-square tests indicated significant differences in the relative composition of *P. maniculatus* and *E. minimus* on replicate plots in similar terrain and habitat type suggesting the use of "representative" plots may not provide adequate descriptions of even species composition of small mammal communities.

Analyses of the fall census data on avifaunal populations indicate:

- The fall season may be an inappropriate period to census avifauna because of the fall migratory behavior of bird species and its effect on sampling precision.
- The mean number of birds sighted per 1.5-km line-transect survey was 16.1, the between-sites variance in bird counts was computed to be 100.04 and the sampling error 18.08. This is a 5-fold difference in the size of variance components.
- When the avifauna survey design accounted for the effects of temporal detectability changes, the CV was 26% for the survey data, however, when blocking for possible temporal effects was ignored the CV for avifauna data increased to 56%. Results suggest that statistical blocking should be used in avifauna monitoring programs.

- The average sighting distance when birds were first detected changed significantly ($\alpha < 0.05$) from day to day, from replicate-to-replicate, and within time of day. suggesting both spatial and temporal effects on detectability. As a consequence it appears that absolute abundance estimators may be needed to provide valid comparisons in avifauna monitoring programs.
- Fall avifauna abundance appears to be too low to permit absolute abundance estimates of bird densities even when 1.5-km line-transects are traversed, suggesting probably the fall period should be omitted in monitoring schemes.
- Among replicate line-transects in similar terrain and habitat type, significant ($\alpha < 0.05$) differences in avifauna composition were observed.

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APPENDIX A

DATA MATRICES FROM SMALL MAMMAL CENSUSES

APPENDIX A

DATA MATRICES FROM SMALL MAMMAL CENSUSES

Data matrices from the mark-removal field procedures for *P. maniculatus* and *E. minimus* at the six study plots in the vicinity of Tract C-a are presented in the following 12 Tables.

TABLE A.1. Summary of Capture Data for Deer Mice
(*Peromyscus maniculatus*) at Site C1

Phase	Trapping Period	Number Marked (X_{im})	Number Unmarked (X_{iu})	Totals
Marking	1	0	11 (+11 mortalities)	M = 19 (+11 marking mortalities)
	2	11	8	
Removal	1	8	10	$n_1 = 18$
	2	2	10	$n_2 = 12$
	3	0	3	$n_3 = 3$
Totals		m = 10	u = 23	r = 33 $t_2 = 18$

TABLE A.2. Summary of Capture Data for Least Chipmunks
(*Eutamias minimus*) at Site C1

Phase	Trapping Period	Number Marked (X_{im})	Number Unmarked (X_{iu})	Totals
Marking	1	0	1	M = 6
	2	0	5	
Removal	1	4	2	$n_1 = 6$
	2	0	3	$n_2 = 3$
	3	0	0	$n_3 = 0$
Totals		m = 4	u = 5	r = 9 $t_2 = 3$

TABLE A.3. Summary of Capture Data for Deer Mice
(*Peromyscus maniculatus*) at Site C2

Phase	Trapping Period	Number Marked (X_{im})	Number Unmarked (X_{iu})	Totals
Marking	1	0	30 (+2 mortalities)	M = 41 (+6 marking mortalities)
	2	23 (+4 mortalities)	15	
Removal	1	23	15	$n_1 = 38$
	2	2	7	$n_2 = 9$
	3	0	7	$n_3 = 7$
Totals		m = 25	u = 23	r = 54 $t_2 = 23$

TABLE A.4. Summary of Capture Data for Least Chipmunks
(*Eutamias minimus*) at Site C2

Phase	Trapping Period	Number Marked (X_{im})	Number Unmarked (X_{iu})	Totals
Marking	1	0	0	M = 1
	2	0	1	
Removal	1	1	2	$n_1 = 3$
	2	0	1	$n_2 = 1$
	3	0	0	$n_3 = 0$
Totals		m = 1	u = 3	r = 4 $t_2 = 1$

TABLE A.5. Summary of Capture Data for Deer Mice
(*Peromyscus maniculatus*) at Site D1

Phase	Trapping Period	Number Marked (X_{im})	Number Unmarked (X_{iu})	Totals
Marking	1	0	16	M = 15 (+8 marking mortalities)
	2	6 (+7 mortalities)	6 (+1 mortality)	
Removal	1	12	16	$n_1 = 28$
	2	2	4	$n_2 = 6$
	3	0	5	$n_3 = 5$
Totals		m = 14	u = 25	r = 39 $t_2 = 16$

TABLE A.6. Summary of Capture Data for Least Chipmunks
(*Eutamias minimus*) at Site D1

Phase	Trapping Period	Number Marked (X_{im})	Number Unmarked (X_{iu})	Totals
Marking	1	0	10	M = 17
	2	10	7	
Removal	1	13	9	$n_1 = 22$
	2	3	1	$n_2 = 4$
	3	0	2	$n_3 = 2$
Totals		m = 16	u = 12	r = 28 $t_2 = 8$

TABLE A.7. Summary of Capture Data for Deer Mice
(*Peromyscus maniculatus*) at Site D2

Phase	Trapping Period	Number Marked (X_{im})	Number Unmarked (X_{iu})	Totals
Marking	1	0	5 (+6 mortalities)	M = 8 (+13 marking mortalities)
	2	2 (+1 mortality)	4 (+6 mortalities)	
Removal	1	6	4	$n_1 = 10$
	2	0	8	$n_2 = 8$
	3	0	2	$n_3 = 2$
Totals		m = 6	u = 14	r = 10 $t_2 = 12$

TABLE A.8. Summary of Capture Data for Least Chipmunks
(*Eutamias minimus*) at Site D2

Phase	Trapping Period	Number Marked (X_{im})	Number Unmarked (X_{iu})	Totals
Marking	1	0	6	M = 12
	2	6	6	
Removal	1	12	4	$n_1 = 16$
	2	0	0	$n_2 = 0$
	3	0	2	$n_3 = 2$
Totals		m = 12	u = 6	r = 18 $t_2 = 4$

TABLE A.9. Summary of Capture Data for Deer Mice
(*Peromyscus maniculatus*) at Site R1

Phase	Trapping Period	Number Marked (X_{im})	Number Unmarked (X_{iu})	Totals
Marking	1	0	6 (+5 mortalities)	M = 8 (+8 marking mortalities)
	2	4 (+2 mortalities)	4 (+1 mortality)	
Removal	1	4	9	$n_1 = 13$
	2	0	6	$n_2 = 6$
	3	0	3	$n_3 = 3$
Totals		m = 4	u = 18	$r = 22$ $t_2 = 12$

TABLE A.10. Summary of Capture Data for Least Chipmunks
(*Eutamias minimus*) at Site R1

Phase	Trapping Period	Number Marked (X_{im})	Number Unmarked (X_{iu})	Totals
Marking	1	0	1	M = 5
	2	1	4	
Removal	1	5	5	$n_1 = 10$
	2	0	8	$n_2 = 8$
	3	0	0	$n_3 = 0$
Totals		m = 5	u = 13	$r = 18$ $t_2 = 8$

TABLE A.11. Summary of Capture Data for Deer Mice
(*Peromyscus maniculatus*) at Site R2

Phase	Trapping Period	Number Marked (X_{im})	Number Unmarked (X_{iu})	Totals
Marking	1	0	8 (+1 mortality)	M = 8 (+3 marking mortalities)
	2	5 (+2 mortalities)	2	
Removal	1	8	5	$n_1 = 13$
	2	0	5	$n_2 = 5$
	3	0	1	$n_3 = 1$
Totals		m = 8	u = 11	r = 19 $t_2 = 7$

TABLE A.12. Summary of Capture Data for Least Chipmunks
(*Eutamias minimus*) at Site R2

Phase	Trapping Period	Number Marked (X_{im})	Number Unmarked (X_{iu})	Totals
Marking	1	0	5	M = 15
	2	5	10 (+2 mortalities)	
Removal	1	11	12	$n_1 = 23$
	2	0	1	$n_2 = 1$
	3	0	1	$n_3 = 1$
Totals		m = 11	u = 14	r = 23 $t_2 = 3$

APPENDIX B

ILLUSTRATION OF THE SMALL MAMMAL DATA ANALYSIS

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ILLUSTRATION OF THE SMALL MAMMAL DATA ANALYSIS

Using the mark-recapture data for *E. minimus*, the calculations for the statistical tests of assumptions and the method for population estimation are illustrated.

TESTS OF HOMOGENEITY

The chi-square test for homogeneous capture probabilities among replicate populations is calculated using the mark-recapture data from the table:

POPULATIONS						
	C1	C2	D1	D2	R1	R2
M-m	2	0	1	0	0	4
u	5	3	12	6	13	14
m	4	1	16	12	5	11
	11	4	29	18	18	29

The chi-square statistic for the 3×6 contingency table is $X_{10}^2 = 16.222$ with 10 degrees of freedom and has a statistical significance of $P(X_{10}^2 \geq 16.222) = 0.093$.

Alternatively, a test of homogeneity also can be computed from the removal data obtained from each study plot. A contingency table analysis can be performed using the removal data in the table:

POPULATIONS

	C1	C2	D1	D2	R1	R2	
n_{1i}	6	3	22	16	10	23	80
n_{2i}	3	1	4	0	8	1	17
n_{3i}	0	0	2	2	0	1	5
r_i	9	4	28	18	18	25	102 = $r_.$
t_{2i}	3	1	8	4	8	3	27 = $t_{2.}$

However, the Q-statistic (Skalski and Robson 1979) is a more powerful test of homogeneity when analyzing removal sampling data. The Q-statistic can be written as

$$Q = \frac{\sum_{i=1}^6 r_i (\bar{y}_i - \bar{y}_.)^2}{s_y^2}$$

and where $\bar{y}_i = t_{2i}/r_i$

$$\bar{y}_. = t_{2.}/r_.$$

$$s_y^2 = \left[\sum_{i=1}^{r_} y_i^2 - \left(\sum_{i=1}^{r_} y_i \right)^2 / r_ \right] / (r_ - 1)$$

The sufficient statistic $t_{2.}$ can be interpreted as the total number of times $r_.$ animals escaped capture prior to being caught and $\bar{y}_.$ is the average number of escapes per animal. Hence, the Q-statistic compares the average "escape rate" for animals in the different populations. Based on the above table, $\bar{y}_. = 27/102$ and $s_y^2 = 0.2956$ resulting in $Q = 4.037$.

The Q-statistic is distributed as Chi-square with 5 degrees of freedom under the null hypothesis and has significance level $P(X_5^2 \geq 4.037) = 0.544$.

TESTS OF ASSUMPTIONS

Pooling the data from the six replicate plots, the goodness-of-fit to a geometric model for removal sampling (Skalski and Robson 1979) can be tested ($n_{1.} = 80$, $n_{2.} = 17$, $n_{3.} = 5$). The test statistic is

$$\hat{Z} = \frac{|n_i - E(n_i | r., t_{2.})| - \frac{1}{2}}{\sqrt{\hat{\text{Var}}[n_i | r., t_{2.}]}}$$

$$\text{when } \hat{E}(n_i | r., t_{2.}) = rA - \frac{AC}{(AB - C^2)} (t_{2.} - r.C)$$

$$\hat{\text{Var}}(n_i | r., t_{2.}) = r. \left[A(1 - A) - \frac{A^2 C^2}{(AB - C^2)} \right]$$

$$\text{and where } A = \frac{\hat{p}}{1 - \hat{q}^3}$$

$$B = \sum_{i=2}^3 (i - 1)^2 \hat{q}^{i-1}$$

$$C = \left(\frac{\hat{q}}{\hat{p}} - \frac{3\hat{q}^3}{1 - \hat{q}^3} \right)$$

The estimated probability of capture, p , is obtained from the maximum likelihood estimators for the removal sampling model (Zippin 1956, 1958) (see page 28). The capture probability is estimated to be $\hat{p} = 0.767535$

($r_1 = 102$, $t_{2.} = 27$) resulting in $A = 0.7773$, $B = 0.4486$ and $C = 0.2647$. The moments are subsequently estimated to be $\hat{E}[n_1 | r_1 = 102, t_{2.} = 27] = 79.2845$ and $\hat{Var}[n_1 | r_1 = 102, t_{2.} = 27] = 2.1597$ with n_1 observed to be 80. The Z-statistic is then computed to be $Z = 0.1466$ with significance $P(Z > 0.1466) = 0.442$.

Using just the unmarked animals captured in each population during the 3-day removal sampling, the goodness-of-fit of unmarked animals can be tested from the data:

POPULATIONS							
	C1	C2	D1	D2	R1	R2	
X_{1u}	2	2	9	4	5	12	$34 = X_{1u.}$
X_{2u}	3	1	1	0	8	1	14
X_{3u}	0	0	2	2	0	1	5
u_i	5	3	12	6	13	14	$53 = u_{.}$
t_{2u_i}	3	1	5	4	8	3	$24 = t_{2u.}$

The capture probability for the unmarked animals is estimated to be $\hat{p} = 0.60766$ ($u_{.} = 53$, $t_{2u.} = 24$) and resulting in $A = 0.6467$, $B = 1.0081$ and $C = 0.4528$. The moments are then estimated to be $\hat{E}[X_{1u.} | u_{.} = 53, t_{2u.} = 24] = 34.2761$ and $\hat{Var}[X_{1u.} | u_{.} = 53, t_{2u.} = 24] = 1.9374$ with an observed value of $X_{1u.} = 34$. The resulting test statistic is $Z = -0.1609$ with a significance of $P(Z > -0.1609) = 0.5639$.

The assumption of equal catchability of marked and unmarked animals is tested using the removal data in the contingency table:

ANIMALS			
	MARKED	UNMARKED	
x_1	46	34	80
x_2	3	14	17
x_3	0	5	5
r_1	49	53	102 = r .
t_{21}	3	24	27 = t_2 .

This test of equal catchability is performed identical to the calculations for the tests of homogeneity used earlier with removal sampling data. Based on the data, $\bar{y} = 27/102$, $S_y^2 = 0.2956$ and resulting in $Q = 13.2100$ with significance level $P(X_1^2 > 13.2100) = 0.0003$.

ESTIMATION OF ABUNDANCE

Results of the tests of assumptions suggest that abundance estimates should be based on removal data for unmarked animals. The estimator chosen estimates the unmarked animals in the populations, and to that are added the numbers of animals captured during the 2-day marking period. The resulting estimates should be robust to the presence of unequal capture rates for marked animals and handling mortalities. The estimator is presented on page 27 of this report.

From the goodness-of-fit test for unmarked animals during the 3-day removal sampling period, the probability of capture is estimated to be $\hat{p} = (1 - \hat{q}) = 0.60766$. Population estimates for each plot are, therefore,

based on the estimator $\hat{p}$, the numbers of unmarked animals caught ($u_i = 5, 3, 12, 6, 13$ and 14 for $i=1, \dots, 6$), and the total number of animals captured per plot during the 2-day live-trapping period ($M_i = 6, 1, 17, 12, 5$, and 15 for $i=1, \dots, 6$). For example, at plot C1 the *E. minimus* abundance is estimated to be $\hat{N}_1 = 6 + 5/(1 - 0.06039) = 11.3$.

APPENDIX C

AVIFAUNA LINE-TRANSECT DATA

APPENDIX C

AVIFAUNA LINE-TRANSECT DATA

The avifauna survey data are listed according to date (16-18, 20 October 1981), site and time of day (morning surveys AM1 and AM2 and afternoon surveys PM1 and PM2). For each sighting, bird species and sighting distance (m) and angle are recorded. Only those observations used for analyses in this report are presented. Sightings from flocks of birds and extreme observations (>200 m) were excluded to minimize problems of heteroschedasticity and lack of independence. Numeric codes associated with the various avifauna species are as follows:

1	white-crowned sparrow
2	sage sparrow
3	song sparrow
4	dark-eyed junco
5	mountain chickadee
6	Cassin's finch
7	mourning dove
8	horned lark
9	western meadowlark
10	robin
11	mountain bluebird
12	Clark's woodpecker
13	hairy woodpecker
14	scrub jay
15	pinyon jay
16	black-billed magpie
17	loggerhead shrike
18	sharp-skinned hawk

<u>Site</u>	<u>Date</u>	<u>Time</u>	<u>Species Code</u>	<u>Distance (m)</u>	<u>Angle (Degrees)</u>
R1	101681	AM1	1	37.0	80
R1	101681	AM1	4	16.0	40
R1	101681	AM1	4	55.0	70
R1	101681	AM1	4	55.0	70
R1	101681	AM1	4	55.0	70
R1	101681	AM1	1	45.1	45
R1	101681	AM1	4	16.5	55
R1	101681	AM1	4	45.1	40
R1	101681	AM1	5	15.0	60
R1	101681	AM1	4	70.0	51
R1	101681	AM1	4	49.0	88
R1	101681	AM1	4	15.0	62
R1	101681	AM1	10	59.0	84
R1	101681	AM1	12	190.0	54
R1	101681	AM1	1	28.5	8
R1	101681	AM1	5	62.0	53
R2	101681	AM2	5	34.0	54
R2	101681	AM2	5	25.5	13
R2	101681	AM2	9	89.0	76
R2	101681	AM2	4	32.0	90
R2	101681	AM2	11	64.0	90
R2	101681	AM2	11	37.0	90
R2	101681	AM2	11	33.0	90
R2	101681	AM2	11	64.0	88
D1	101681	PM1	4	7.5	57
D1	101681	PM1	8	13.5	52
D1	101681	PM1	8	13.5	52
D1	101681	PM1	8	17.0	112
D1	101681	PM1	8	17.0	112
D1	101681	PM1	8	17.0	112
D1	101681	PM1	8	17.0	112
D1	101681	PM1	8	17.0	112
D1	101681	PM1	8	17.0	112
D1	101681	PM1	4	41.0	52
D1	101681	PM1	4	33.0	76
D1	101681	PM1	4	16.0	45
D1	101681	PM1	4	16.0	45

<u>Site</u>	<u>Date</u>	<u>Time</u>	<u>Species Code</u>	<u>Distance (m)</u>	<u>Angle (Degrees)</u>
D1	101781	AM1	4	5.3	90
D1	101781	AM1	4	5.3	90
D1	101781	AM1	4	65.0	10
D1	101781	AM1	4	39.0	2
D1	101781	AM1	4	36.0	4
D1	101781	AM1	4	37.0	10
D1	101781	AM1	4	45.0	22
D1	101781	AM1	4	45.0	22
D1	101781	AM1	4	45.0	22
D1	101781	AM1	4	41.0	30
D1	101781	AM1	4	41.0	30
D1	101781	AM1	4	41.0	30
D1	101781	AM1	4	29.8	50
D1	101781	AM1	4	29.8	50
D1	101781	AM1	4	29.8	50
D1	101781	AM1	4	29.8	50
D1	101781	AM1	4	29.8	50
D1	101781	AM1	5	32.5	70
D1	101781	AM1	1	26.0	15
D1	101781	AM1	1	28.0	5
D1	101781	AM1	4	4.5	25
D1	101781	AM1	4	12.8	58
D1	101781	AM1	4	21.5	27
D1	101781	AM1	4	32.0	72
D1	101781	AM1	4	32.0	72
D1	101781	AM1	4	75.0	74
D1	101781	AM1	4	75.0	74
D1	101781	AM1	4	75.0	74
D1	101781	AM1	13	31.0	40
D1	101781	AM1	4	40.0	73
D1	101781	AM1	4	55.0	90
D1	101781	AM1	4	23.0	36
D1	101781	AM1	1	37.0	60
D1	101781	AM1	4	36.0	52
D1	101781	AM1	4	27.0	75
D1	101781	AM1	1	20.0	50
D1	101781	AM1	17	32.0	50
D1	101781	AM1	2	31.0	57
D1	101781	AM1	1	55.0	11
D1	101781	AM1	1	55.0	11
D1	101781	AM1	1	55.0	11
D1	101781	AM1	1	55.0	11
D1	101781	AM1	1	25.0	20
D1	101781	AM1	4	40.0	69
D1	101781	AM1	4	40.0	69
D1	101781	AM1	4	40.0	69
D1	101781	AM1	4	40.0	69
D1	101781	AM1	4	40.0	69

<u>Site</u>	<u>Date</u>	<u>Time</u>	<u>Species Code</u>	<u>Distance (m)</u>	<u>Angle (Degrees)</u>
D2	101781	AM2	1	17.0	40
D2	101781	AM2	1	17.3	60
D2	101781	AM2	2	9.0	60
D2	101781	AM2	2	24.5	25
D2	101781	AM2	2	34.0	30
D2	101781	AM2	9	104.0	40
D2	101781	AM2	16	42.0	48
D2	101781	AM2	16	42.0	48
D2	101781	AM2	14	80.0	10
D2	101781	AM2	4	12.0	50
D2	101781	AM2	4	12.0	50
D2	101781	AM2	4	12.0	50
D2	101781	AM2	4	12.0	50
D2	101781	AM2	4	25.5	90
D2	101781	AM2	1	8.3	22
R1	101781	PM1	4	36.0	85
R1	101781	PM1	4	36.0	85
R1	101781	PM1	18	102.0	20
R1	101781	PM1	4	13.0	5
R1	101781	PM1	6	101.0	28
R1	101781	PM1	6	101.0	28
R1	101781	PM1	6	101.0	28
R1	101781	PM1	6	101.0	28
R1	101781	PM1	6	101.0	28
R1	101781	PM1	6	101.0	28
R1	101781	PM1	4	25.2	90
R1	101781	PM1	4	28.5	90
R1	101781	PM1	4	28.5	90
R1	101781	PM1	4	14.5	50
R1	101781	PM1	4	14.5	50
R1	101781	PM1	4	14.5	50
R1	101781	PM1	4	20.5	15
R1	101781	PM1	4	20.5	10
R1	101781	PM1	4	22.0	7
R1	101781	PM1	4	28.5	40
R1	101781	PM1	4	15.5	20
R1	101781	PM1	4	6.8	60

<u>Site</u>	<u>Date</u>	<u>Time</u>	<u>Species Code</u>	<u>Distance (m)</u>	<u>Angle (Degrees)</u>
R2	101781	PM2	4	26.5	80
R2	101781	PM2	4	26.5	80
R2	101781	PM2	4	26.5	80
R2	101781	PM2	8	17.8	20
R2	101781	PM2	4	10.5	30
R2	101781	PM2	1	29.0	60
R2	101781	PM2	1	29.0	60
R2	101781	PM2	1	29.0	60
R2	101781	PM2	1	29.0	60
R2	101781	PM2	1	29.0	60
R2	101781	PM2	1	29.0	60
R2	101781	PM2	4	34.0	37
R2	101781	PM2	4	34.0	37
R2	101781	PM2	4	20.0	15

<u>Site</u>	<u>Date</u>	<u>Time</u>	<u>Species Code</u>	<u>Distance (m)</u>	<u>Angle (Degrees)</u>
R2	101881	AM1	4	4.5	5
R2	101881	AM1	5	35.0	26
R2	101881	AM1	1	19.0	60
R2	101881	AM1	1	85.0	45
R2	101881	AM1	1	60.0	40
R2	101881	AM1	1	60.0	40
R2	101881	AM1	1	80.0	40
R2	101881	AM1	1	52.0	35
R2	101881	AM1	1	52.0	40
R2	101881	AM1	1	42.5	5
D1	101881	AM2	4	18.2	90
D1	101881	AM2	4	21.5	83
D1	101881	AM2	4	21.5	83
D1	101881	AM2	8	20.5	66
D1	101881	AM2	4	4.5	90
D1	101881	AM2	1	7.5	55
D2	101881	PM1	4	31.0	12
D2	101881	PM1	18	18.5	75
D2	101881	PM1	11	24.5	52
D2	101881	PM1	2	7.5	18
D2	101881	PM1	4	22.8	66
D2	101881	PM1	5	36.0	90
D2	101881	PM1	5	36.0	90
D2	101881	PM1	5	36.0	90
D2	101881	PM1	5	92.0	88
R1	101881	PM2	4	44.0	80
R1	101881	PM2	4	80.0	2
R1	101881	PM2	4	80.0	7
R1	101881	PM2	4	39.0	22
R1	101881	PM2	4	21.5	43
R1	101881	PM2	14	22.0	38

<u>Site</u>	<u>Date</u>	<u>Time</u>	<u>Species Code</u>	<u>Distance (m)</u>	<u>Angle (Degrees)</u>
D2	102081	AM1	7	16.0	72
D2	102081	AM1	4	31.0	42
D2	102081	AM1	4	31.0	42
D2	102081	AM1	4	22.0	66
D2	102081	AM1	1	34.0	40
D2	102081	AM1	1	31.0	80
D2	102081	AM1	1	42.0	60
D2	102081	AM1	2	50.0	90
D2	102081	AM1	1	14.0	10
D2	102081	AM1	1	24.0	82
R1	102081	AM2	4	5.0	20
R1	102081	AM2	4	12.0	45
R1	102081	AM2	4	12.0	45
R1	102081	AM2	4	7.0	60
R1	102081	AM2	4	12.0	30
R1	102081	AM2	4	18.0	22
R1	102081	AM2	4	37.0	18
R1	102081	AM2	4	6.0	8
R1	102081	AM2	4	6.0	8
R1	102081	AM2	4	14.0	50
R1	102081	AM2	4	17.0	65
R2	102081	PM1	17	68.0	76
R2	102081	PM1	4	19.0	16
R2	102081	PM1	5	60.0	90
R2	102081	PM1	5	60.0	90
R2	102081	PM1	5	22.0	80
R2	102081	PM1	5	24.5	28
D1	102081	PM2	2	51.5	15
D1	102081	PM2	4	10.5	12
D1	102081	PM2	4	9.8	14
D1	102081	PM2	4	22.0	45
D1	102081	PM2	4	20.8	55
D1	102081	PM2	4	20.8	55
D1	102081	PM2	4	20.8	55
D1	102081	PM2	4	14.0	70
D1	102081	PM2	4	14.0	70
D1	102081	PM2	4	14.0	70
D1	102081	PM2	4	10.5	70
D1	102081	PM2	4	10.5	70
D1	102081	PM2	4	21.5	54
D1	102081	PM2	4	36.5	26

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