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PREDICTION AND MONITORING OF RODENT ABUNDANCE IN AGRICULTURAL AREAS OF CHAD, AFRICA

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by

Trent L. McDonald
Lyman L. McDonald
Western EcoSystems Technology, Inc.
1402 South Greeley Highway
Cheyenne, Wyoming 82007

Prepared for

Denver Wildlife Research Center
USDA APHIS ADC
Building 16, Denver Federal Center
P. O. Box 25266
Denver, Colorado 80225-0266

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EXECUTIVE SUMMARY

1. The Agency for International Development (AID) and the Denver Wildlife Research Center (DWRC) in cooperation with the Government of Chad, conducted a research program during 1989-1991 to determine the species involved in recent increases in rodent abundance, rodent population dynamics, and effective control measures.

2. This report contains an analysis of data collected during the DWRC study, with emphasis on reducing sampling effort in a long term monitoring program and development of models for prediction of chronic annual increases in rodent abundance.

3. The data set analyzed does not provide inductive (statistical) inferences for prediction of periodic major irruptions in abundance of rodents because no major irruptions were observed during the course of data collection.

4. Sites selected for study were wadi and dune cultivated areas near N'Gouri, Chad, and in areas close to Karal, Chad, that are periodically flooded by Lake Chad and left dry when the lake recedes.

5. Focus of the modeling effort is on the three most common species of rodents found on the study areas (Nile or unstriped grassrat (Arvicanthis niloticus), gerbils (Gerbillus andersoni), and multimammate rats (Mastomys[Praomys] spp.)) as well as on the total number of rodents regardless of species.

6. Rodents were collected by trapping with "rat" and "mouse" snap traps located along linear transects within fields. Sampling effort is a function of the number of sampling trips, the number of fields trapped, number of transects per field and number of traps per transect.

7. The index on abundance which was used as a dependent variable in the model building phase was (square root of) trap success, where trap success was computed as:

$$p = n_{Ai} / t_i$$

where,

n_{Ai} = number of animals of species A caught on transect i, and

t_i = number of "effective" traps on transect i.

8. The number of effective traps was computed as the number of traps set on transect i minus the number of traps which were lost on transect i minus the number of traps sprung but empty on transect i minus the number of traps catching animals other than the target species on transect i. Correlations with the alternative definition when one subtracts 50% of the number of traps sprung, lost or which caught other species were: 0.988 for Nile rats, and 0.996 for all rodent species combined. Only the first definition is considered in this report.

9. Independent predictor variables considered in the modeling effort were: average 10 day (total) rainfall during a given month lagged by 1,2,3,...months, Normalized Vegetative Difference Index (NVDI) on the amount of green vegetation present lagged by 1,2,3,...months (collected by the National Oceanic and Atmospheric Administration from satellites), proportion of adult females which are pregnant lagged by 1,2,3,...months, and the index on trap success lagged by 1,2,3,...months.

10. Criteria for model fitting were to obtain the simplest (most parsimonious) model with statistically significant coefficients while approaching the maximum proportion of variation explained and in which the coefficients were theoretically defensible in the sense that they have the "correct sign" based on deductive arguments.

11. Models are developed and recommended for prediction of (square root of) trap success two months in advance based on rainfall measured two months in the past

and the current value of trap success for three cases: "all rodent species", Nile rats, and gerbils. The same model is recommended for all three of the locations: wadis and dunes at N'Gouri, and recessional farms at Karal. No models with statistically significant coefficients were obtained for prediction of trap success for multimammate rats.

12. Models which can be applied to different sites and combinations of species are recommended because they are easier to use and with professional judgement can be regarded as an approximation to predicted future trap success in areas other than the ones examined in this study.

13. The models can be expected to correlate well with normal chronic cycles similar to those found in the existing data set but, only with fortuitous luck, will the models preform well in predictions of more dramatic increases in the abundance indices.

14. The model for trap success on all rodent species was used to predict trap success during hypothetical cycles in rodent population abundance. Even though there were no major increases in rodent numbers during the course of this study, if the trapping success is high during the dry season then combined with an increase in rainfall during the following rainy season, the present models will predict increases in trapping success and have (limited) potential to yield estimates which will correlate with later observed trap success. However, the model has difficulty predicting the magnitude of indices outside the range of observed data.

15. A Monte Carlo computer simulation was conducted to subsample the observed data and examine the behavior of predictions for trap success when fewer fields, transects, and traps are sampled per trip. Precision of predictions under the reduced sampling effort were compared with precision of predictions of a density index using the entire observed data set.

16. Graphs of contour lines are given which can be used to balance the savings of reduced sampling effort in wadis for each of the components (number of fields, number of transects/field, and number of recovered traps/transect) against the expected decrease in prediction variance relative to the present study. For example, with 6 fields, 4 transects/field, and approximately 11 recovered traps/transect one can expect an increase in prediction standard error of approximately 112% relative to the present study. Reducing the sampling effort in wadis to approximately half of that in the present study (to 5 fields, 3 transects/field, and 10 recovered traps/field) is projected to increase the prediction standard error to approximately 122% of that observed in the present study.

17 The recommended months for sampling rodents are: June through September with no sampling October through May unless rodent numbers, model predictions, or professional judgement indicate that an "outbreak" is developing. Given rainfall from April and trap success from June, trapping success is estimated for August. Similarly, estimates can be obtained for September, October, and November based on four months of rodent sampling.

18. Recommendations for further research.

18.1 Develop written standard operating procedures for all aspects of the trapping project including:

18.1.1 selection of trapping sites, transects within sites and traps within transects

18.2 Consider use of probability based sampling for trapping sites. Extrapolation of the results of the present study is based on assumptions, not inductive inferences.

18.3 Evaluate the models using data collected during 1992:

18.3.1 Trapping success during 1992 is apparently higher than during most of the 1989-1991 period. Evaluate the precision and accuracy of predictions by the present models which are extrapolated beyond the range of data used to develop the models.

18.3.2 Assuming extrapolations from the present models are less than satisfactory, modify models based on a broader data base.

INTRODUCTION

The Sahel region of Africa encompasses about twenty percent of Africa and includes portions of nine African nations, with a population of about 30 million people (Indicateurs Demographiques et Socio-Economiques des Pays Membres du CILSS--1989). The Sahel region previously was a major food-producing area for northern Africa, but in 1986 several Sahelian nations declared national disasters due to drought and crop depredations by major increases in abundance (outbreaks) of rodents (Wilson 1990). Periodic rodent outbreaks, such as those of 1962, 1977, and 1986-87 (Fiedler 1987, as reported by Spillet and Brooks 1991), probably have occurred in the Sahel region for centuries (Spillet and Brooks 1991). Although Sahelian rodent outbreaks often have been widespread and have severely reduced food production, these phenomena are difficult to document and predict.

The Agency for International Development (AID), Washington DC, in cooperation with the Government of Chad, developed a research program to determine the species of rodents involved in the outbreaks as well as rodent population dynamics and effective control measures (Wilson 1990). This report contains an analysis of data collected during the ensuing study, with emphasis on reducing sampling effort in a long term monitoring program and development of models for prediction of increases in rodent abundance Cost efficient monitoring methods and reliable models are critical tools to help national crop protection decision-makers to make informed decisions concerning chronic annual fluctuations, to forecast periodic rodent irruptions, and to begin control campaigns with the maximum lead time (Wilson 1990).

Sites selected for study by the Agency for International Development (AID), in cooperation with the government of Chad were agricultural areas near N'Gouri and Karal, Chad (Wilson 1990, Spillet and Brooks 1991). The N'Gouri region is approximately 230 km north of N'Djamena, Chad, and contains two types of cultivation methods; cultivation in wadis, and cultivation on dunes. Wadi cultivation is a labor-intensive operation with irrigation and cultivation of a variety of agricultural crops in scattered, small oases (Spillet and Brooks

1991). Dune cultivation is extensive, dryland farming of millet (Spillet and Brooks 1991). The Karal region is approximately 100 km south west of the N'Gouri region and contains fields which were planted in areas that are periodically flooded by nearby Lake Chad and left dry when the lake recedes (Spillet and Brooks 1991).

Focus of the modeling effort is on the three most common species of rodents found on the study areas near N'Gouri and Karal, as well as on the total number of rodents regardless of species. The three major species of rodents found on the study sites were the Nile or unstriped grassrat (Arvicanthis niloticus), gerbils (Gerbillus andersoni), and multimammate rats (Mastomys[Praomys] spp.).

The methods section of this paper contains a brief description of the field sampling procedure carried out between October 89 and December 91 based on the reports of Spillet and Brooks (1991), Wilson (1990), and personal communication with Denver Wildlife Research Center (DWRC) staff members Joe Brooks, Lynn Fiedler, Rick Bruggers, and former staff member Keith LaVoie. Also reported in the methods section is a description of procedures used in construction of the predictive model for levels of trapping success (which is assumed to correlate with rodent population size) at a future point in time and procedures for making recommendation on reduced sampling effort. The results section of this paper contains a brief summary of background information on species captured, as well as the fitted models and recommendations for reduced sampling effort. In the discussion section of this paper, implications of the sampling scheme and models are discussed and recommendations are given for future work.

METHODS AND MATERIALS

Field Methods:

N'Gouri Area (Spillet and Brooks 1991)

Rodent sampling sites were selected in late 1989 in typical wadi and dune cultivations in the N'Gouri area, approximately 230 km northwest of N'Djamena. Wadi cultivation involves labor-intensive irrigation and cultivation of onions, tomatoes, peppers, okra, manioc, sorghum, and millet in scattered, small (< 5 ha) oases. Dune cultivation is extensive dryland farming of millet on dunes or sandy hills surrounding the wadis. Both cultivations are done entirely by hand.

Rodent sampling was initiated in October 1989 and trapping was conducted approximately monthly thereafter. One wadi site was added in June 1990 and two others in July 1990. If a wadi was not in production at the time of field sampling, it was not sampled for rodents. Animals were trapped on linear transects with 25 stations (one rat snap trap at each station) at 10 m intervals. Six transects were set at each wadi. One transect was set in non-cultivated margin of the wadi, one transect was set in non-cultivated interior, another in the cultivated margin, another in cultivated interior, and two in non-cultivated exterior. Figure 1, reproduced from Spillet and Brooks (1991) Figure 1, shows typical locations for the six transects on wadis at N'Gouri. Transects exterior to the wadis differed from transects interior to the wadis by having one rat snap trap and one mouse snap trap at each of the 25 stations. It was not possible to distinguish captures by the rat traps from captures by the mouse traps in the data sets analyzed. In most of the statistical work which follows, trapping success for organisms is calculated for the entire wadi combining data from all six transects because of the small numbers of individuals captured and relatively large coefficient of variation observed on individual transects. Small (15-20 mm^2) pieces of cardboard impregnated with peanut oil were used for baits, following the suggestion of Wilson after his 1989 visit (Wilson 1990). Traps were set in late afternoon, left overnight, and collected the

next morning (DWRC personnel, personal communication). Three dune sites were sampled monthly beginning in November 1989; one more dune site was added in July 1990. Two linear transects of 50 stations, using mouse snap traps were set at 10 m intervals on each dune. Trapping effort on all wadis and dunes required 7 to 8 days, which combined with 7 to 8 days at the Karal site made sampling trips of approximately 15 days each (DWRC personnel, personal communication).

Trapped rodents were identified to species, and data were recorded for sex, weight, age class (immature or adult), and reproductive condition on each animal.

Karal Area (Spillet and Brooks 1991)

Rodent population sampling was initiated in August 1990 on recessional agricultural crops or adjacent vegetative types in the Karal area, south of Lake Chad and approximately 130 km north of N'Djamena. Recessional agriculture is the planting of crops on lands that are flooded each year by the waters of Lake Chad as a result of the rainy season. As the waters recede and the lands dry, rice, corn, sorghum, millet, cow peas, peanuts, manioc, okra, sweet potatoes, water melon, cantaloupe, gourds, and tomatoes are planted.

Rodent populations were sampled in a wide variety of crop types and in adjacent vegetation types with linear transects of 25 stations (one rat snap trap and one mouse snap trap at each station) spaced 10 m apart. Fields at Karal regularly were taken out of production as part of the customary farming process. Fields not in production at the time of a sampling trip were not trapped. The same data were recorded for trapped rodents as in the N'Gouri area.

Species Identification

Personnel of the Denver Wildlife Research Center (DWRC) traveled to the N'Gouri area in fall 1992 and collected recent specimens (Joe Brooks, personal communication). Several specimens of unidentified rodents were collected and sent to the U.S. National Museum in Washington, D.C. for identification. Based on identifications made at the museum and by DWRC personnel, all Gerbillus andersoni greater than 40 grams were recoded to Tatera robusta/Taterillus lacustris, all Mus sp. greater than 20 grams were recoded to Mastomys sp., and a subset of specimens previously unidentified were determined to be Tatera robusta.

Model Building:

Index of Rodent Abundance

Primary interest is in an index of abundance which is assumed to vary in accordance with true population abundance. The primary index calculated is termed "trap success", and is computed as:

$$p = n_{Ai} / t_i$$

where,

p = index on abundance (ie. trap success)

n_{Ai} = number of animals of species A caught on transect i

t_i = number of "effective" traps on transect i

To compute t_i, the number of effective traps, it is necessary to consider the five fates of traps in this study. A trap could either catch a species of interest (say species A), catch a species which was not of interest (not species A), be sprung but not catch anything, be lost and unrecoverable, or remain untripped and empty. The quantity t_i (number of effective traps) was computed as the number of traps set on transect i minus the number of traps which

were lost on transect i minus the number of traps sprung but empty on transect i minus the number of traps catching animals other than the target species (eg. species A) on transect i. An alternative definition (where 50% of the number of traps sprung, lost or which caught different species was subtracted from the number of traps set) was evaluated by computing the correlation of its value with the value obtained by the above definition. Correlations were 0.988 for the two definitions of trap success for Nile rats, 0.996 for all rodent species combined, and 0.896 for gerbils. Only the first definition is considered further in this report because:

1. this definition was used in previous analyses of these data by DWRC personnel (Keith LaVoie, Lotus 123 spreadsheets and personal communication), and
2. primary interest is in prediction of trap success for Nile rats and for all rodent species combined where the two definitions have high correlation.

A mathematical transformation of p, the variable trap success, was sought which would reduce the variance of p as well as transform p to be approximately normally distributed. Visual inspection of histograms indicated that the distribution of p was skewed with more values in the lower tail near zero. Both the natural logarithm of p and the square root of p (times a scaler multiple to make the transformation have approximately one digit to the left of the decimal point) were computed and histograms of the transformations indicated that the square root transformation produced a nearly symmetric distribution while reducing the variance of p. The logarithm transformation of p produced a distribution which was even more highly skewed than the original. The square root transformation was selected and used as one dependent variable of interest throughout the remainder of the model building phase. This index on abundance, the square root of trapping success (times the scaler 1000), will be referred to as "trap success" in the remainder of the report unless it is necessary to emphasize that the square root transformation is involved.

A second mathematical transformation of trap success was considered in the model building phase. This transformation resulted in a second index on abundance of rodents which was called "density index" in this report. The index is defined as $di = -\ln(1-p)$, where p is trap

success computed above. This index on abundance of rodents has been used in the past by researchers at DWRC (Rick Bruggers, personal communication; Keith LaVoie, Lotus 123 Spreadsheets). The present study provided an opportunity to study these indices and compare their relative correlation with rainfall and other predictor variables.

Rainfall and NVDI variables

Rainfall was measured in millimeters at three sites at or near the study areas. Rainfall site 1 was at N'Gouri, rainfall site 2 was at Bol-Matafo which is 40 kilometers west of N'Gouri, and rainfall site 3 was at Massakory S/P which is 65 kilometers south-south east of N'Gouri. Values for rainfall at these sites from mid-1989 to December 1991 were provided by DWRC personnel. At each rainfall site, total rainfall for a ten day period was recorded three times each month. These three values were averaged to obtain an independent predictor variable for rainfall during a given month because, the rodent density indices are recorded only on a monthly basis and there were missing observations for many of the ten day periods. Note that the average ten day rainfall and the total rainfall for the month are equivalent predictor variables in the models considered (one can be obtained from the other by using the constant factor 3).

Figure 2 shows average ten day rainfall for each month at each of the sites during the course of the study. Rainfall at one site, N'Gouri, is a candidate as a predictor variable for future values of indices of rodent density at trapping locations close to N'Gouri. Also, combining monthly rainfall across the three sites was deemed feasible and prudent in the search for simple, general independent predictor variables for prediction of future values of indices on rodent density because rainfall was not measured at each trapping location and local variation in rainfall is expected. To compute average ten day rainfall for each month, a two step averaging process was employed where the first step averaged the three (ten day total) rainfall values for a given month at a site and the second step averaged the month averages across the three sites. This "average of averages" was then used as a potential explanatory variable in the models for prediction of the rodent abundance indices.

Normalized Vegetative Difference Index (NVDI) is an index on the amount of green vegetation present, obtained from satellite data collected by the National Oceanic and Atmospheric Administration (NOAA) during 1989, 1990, and 1991 (DWRC personnel, personal communication). NVDI ranges from -1.0 to 1.0 with values less than 0.1 indicating dry conditions, values between 0.1 and 0.2 indicating emergence of vegetation, values between 0.2 and 0.25 indicating generalized pastures, and values above 0.25 indicating increasing vegetative vigor. NVDI was recorded for N'Gouri three times each month, once in each ten day period. The three NVDI values in each month were averaged to obtain one NVDI number per month as a potential predictor variable for future density indices. As with rainfall, values of NVDI at N'Gouri for 1989, 1990, and 1991 were provided by DWRC personnel.

Pregnancy variables

Proportion of pregnant adult females of any species was computed as the ratio of total number of pregnant adult females on all transects at a site (wadi, dune, or field at Karal) to total number of adult females on all transects at a site. However, the incidence of capture of adult females was so infrequent and variable that inclusion of this index as a predictor variable for future values of indices on rodent density was not practical. Consequently, the number of pregnant adult females of any species was summed over all transects and all sites for a given trip. The total number of adult females of any species, both pregnant and non-pregnant, was obtained for the same transects at all sites within a trip. The proportion of pregnant females, calculated for each trip, was then the ratio of total pregnant females on all transects to total females on all transects. This variable was considered as a potential predictor of future values of the indices on rodent density.

Lagged Explanatory Variables

For the purpose of predicting one of the indices on rodent density at a future point in time, a partially autoregressive model was fitted to the data. A lagged variable is defined to be the value of the variable at a point in the past. Explanatory variables considered in the model building process were rainfall lagged one or more months, normalized vegetative difference index (NVDI) lagged one or more months, proportion of pregnant females lagged one or more months, and the value of the density index lagged by one or more months. Use of the models in practice will involve measurement of the present values of significant predictor variables and prediction of abundance indices at a future point in time equal to the minimum lag on predictor variables. Larger values for lag time allow predictions of abundance indices at a more distant point in the future.

Model Fitting

Table 1 contains the lags (in months) producing significant correlation between trap success (square root transformed as $\sqrt{(p*1000)}$) and explanatory variables for the species and sites indicated. For example, by focusing on all species captured in wadis one can note that rainfall in the current month had significant correlation with observed trap success four months in the future; NVDI was not significantly correlated for any lags considered; percent pregnant adult females (%Preg) had a spurious significant negative correlation at lag 5 months; and trap success was significantly correlated with itself at lags 1, 2, 3, and 4 months. Correlations were computed as regular Pearson correlation coefficients and a correlation was deemed significant if its significance level (p-value) was below 10%. Note that a significant negative correlation of t months is denoted as (t) in Table 1.

For modeling abundance indices, no requirement was made for equal lags across variables, sites, or species. Various combinations of lags in the explanatory variables were selected and fit to observed data. The final set of lags selected for the prediction of indices on rodent abundance in the future were those which yielded the simplest (most parsimonious) model

with significant coefficients while approaching the maximum proportion of variation explained and whose coefficients were theoretically defensible in the sense that they have the correct sign based on deductive arguments. When building models for the abundance indices of individual species, not all coefficients in a certain "target set of variables" were required to be significant. This process is further defined below.

During model building, three separate models were fitted, one for dunes, wadis, and Karal, and statistically tested to see if compelling evidence existed which indicated the models should remain separate (null hypothesis of equality of the coefficients). Gerbils (Gerbillus andersoni) were predominately found on dunes (with Jaculus jaculus and rarely; Tatera robusta or Taterillus lacustris) while nile rats (Arvicanthis niloticus) were found inside wadis (with Tatera robusta, Taterillus lacustris, and rarely; Mastomys) but not on the surrounding dunes (DWRC personnel, personal communication). This implies a fundamentally different species composition on wadis and dunes which in turn implies potentially different models for prediction of future values of the abundance indices. Also, the Karal site was approximately 100 kilometers from the wadis and dunes sites with primarily gerbils (Gerbillus andersoni), Taterillus lacustris, Mastomys, and Mus. Separation by distance or different species composition may imply that fundamentally different models are needed at each site. By estimating the models separately and testing the hypothesis that they could be combined, the model fitting process potentially allowed for different models at dunes, wadis, and Karal.

Starting with all rodent species combined, the full model for prediction of an index on density at a future point in time included all explanatory variables. This full model was fitted to observed data at each site (i.e., dunes, wadis, and Karal), and models were successively combined and variables were eliminated when statistical tests indicated this was feasible. This backward elimination of terms in the model was continued until a most parsimonious model was arrived at which had significant coefficients and was theoretically defensible in that all coefficients had the "correct" sign. The variables remaining in the model for abundance index of all species were then used as a "minimal structural form" for the models

to predict individual species abundance indices. That is, for each individual species, the model building process for prediction of indices on abundance started with all explanatory variables. Variables which were significant in the prediction of abundance indices for all species combined were retained while others were discarded if they were non-significant in the statistical tests. Thus, the variables in the "all species model" was a minimal set and it was recognized that some coefficients for variables in the "individual species models" might not be significantly different from zero.

Model fitting was by standard linear least squares estimation and tests were conducted assuming Normally distributed errors. All model estimation was conducted using the SAS procedure GLM and type III sums of squares obtained from GLM's MODEL, ESTIMATE, and CONTRAST statements (SAS, 1988).

Model Behavior

To investigate the behavior and ability of the estimated linear models to predict the observed annual cycles, residual plots were constructed and analyzed. Also, the models were subjected to cycles of hypothetical increases and decreases in the abundance indices for rodent populations (e.g., cycles of dramatic increases in trapping success followed by less dramatic decreases in abundance; leading to an "outbreak" over a two-three year period). Testing the constructed linear models under hypothetical population cycles was preformed because cycles with dramatic swings in population numbers were not observed during the study period and the basic behavior of the models under this situation was unknown. Data indicated that the length of the rainy season was approximately five months (Figure 2) with a peak in the average 10 day total of about 30 millimeters about three months after the start of rainfall. Hypothetical abundance index values were constructed under two scenarios; one scenario was for trapping success to increase approximately four months after rain, remain at an elevated level and to increase again after rainfall in two subsequent years; the second scenario was for trapping success to increase to levels roughly four times the level of the

majority of observed data (90% of observed data on transformed trap success was between 0 and 25). Once the hypothetical rainfall values and rodent capture rates were established, the model was used to predict trap success two months into the "future". The hypothetical capture rates and the predicted capture rates were then plotted on the same graph and visually analyzed for consistency. We emphasize that this exercise was conducted only to explore the basic behavior of the models. The models can be expected to correlate well with normal annual cycles similar to those found in the existing data set but, only with fortuitous luck, will the models preform well in predictions of more dramatic increases in the abundance indices.

Reduced Sampling Effort Determination

The goal of this portion of the study was to study the effects of reduced field sampling effort on model predictions of rodent abundance indices. There are four levels of field sampling to consider; trips, fields within trips, transects within fields, and traps within transects. During the determination of precision of reduced sample sizes, we use the more generic term field to refer to wadis. A Monte Carlo computer simulation was conducted to subsample the observed data and examine the behavior of predictions on abundance indices when fewer fields, transects, and traps are sampled per trip. Predictions under the reduced sampling effort were compared with predictions of an abundance index using the entire observed data set. A sampling scheme for predicting rodent abundance based on fewer trips, fields, transects, and traps is discussed in the Results and Discussion Section.

Data on individual fields, transects, and traps were subsampled, with replacement, from the particular months required by the predictor variables in the final fitted model for all rodent species combined. Observed rainfall and rodent abundance from the subsample were substituted into the model to yield a prediction of trap success ($\sqrt{(p*1000)}$). The process of predicting trap success from subsamples was repeated for each month of the study. The sum of differences squared (SDS) between predicted trap success based on a reduced

sample and observed trap success in the full sample was computed and used to measure the "closeness" of the reduced sampling effort to the full sampling effort. As the amount of sampling effort in the simulation increased to the total sampling effort in the field study, the simulated sum of differences squared approaches the observed sum.

Twenty-seven different sampling scenarios were simulated, each representing a combination of low, medium, or high level of sampling effort for each of fields, transects, and traps (i.e., there are $3^3 = 27$ combinations). During simulations, the number of trips was fixed at the actual number of trips in the original data set, twenty-two. Simulations focused on predicting the trap success for numbers of all species on **wadis only** at N'Gouri so that "field" refers to wadis. The numbers of wadis simulated were 3, 6, and 10 with 2, 4, and 6 transects within fields, and 5, 10, and 20 traps within transects. The combination of 10 fields, 6 transects per field, and 20 traps per transect roughly corresponds (discounting lost traps) to the actual level of field sampling conducted in Chad. The ratio of the SDS for each of the 27 cases to the SDS for the full sampling scheme (ie. 10 fields, 6 transects, and 20 traps) was computed. Contour lines on the resulting surface were plotted and visually analyzed for combinations of sampling effort which give approximately equal prediction variance.

RESULTS AND DISCUSSION

Species Found:

A total of 877 animals were captured on all wadis, dunes, and recessional fields during the entire study period (Table 2, species names used in Table 2 are listed in Table 3). During the entire study period on wadis at N'Gouri, Arvicanthis niloticus comprised 55% of all animals captured, followed by Gerbillus andersoni comprising 27% and Tatera robusta/Taterillus lacustris comprising 12%. Five percent of the animals were not identified. On dune sites at N'Gouri, the predominate species was Gerbillus andersoni comprising 95% of all animals captured. Five (3%) of the animals captured on dunes were not identified. In the recessional fields at Karal, Mastomys spp. was found to be the dominant rodent

species (45%), followed by Tatera robusta/Taterillus lacustris (23%), Gerbillus andersoni (17%), and Mus spp. (15%).

Model Building:

Two explanatory variables, NVDI and proportion of pregnant females, were eliminated from consideration in any model because NVDI was highly correlated with rainfall (i.e., NVDI and rainfall were collinear) and because the proportion of pregnant females contained few usable observations due to low or zero catches of females. The collinearity of rainfall and NVDI became evident when the signs and relative magnitudes of estimated coefficients changed dramatically according to whether one or both were in the model. For proportion of pregnant females, there were few total catches totaling more than one or two females of any species after about January 90, and thus when a female was captured the proportion pregnant was likely either 0% or 100%. After January 1990, there were only 60 females of any species captured, 21 of which were pregnant, during 12 distinct trips. Of the 19 trips to N'Gouri between January 1990 and December 1991, representing 23,600 set traps, seven trips captured no females of any species precluding the computation of the predictor variable.

The final set of lags in the explanatory variables was four months for rainfall (average 10 day total) and two months for indices on rodent abundance. Other lags, while sometimes producing significant estimated coefficients, resulted in more complicated models which often were not defensible from a biological point of view and the proportion of variance accounted for (R^2's) were all about the same (around 0.80) or lower than that for lags of four months for rainfall and two months for abundance indices. For example, rainfall lagged by 2 months on dunes, 2 months on wadis, and 2 months at Karal, and trap success lagged by 2 months on dunes, 2 months on wadis, and 2 month at Karal produced a model in which the coefficient of lagged rainfall was negative and moderately significant (P-value = 0.104). A negative coefficient for lagged rainfall is not defensible from a biological point of view.

A single lag period of 4 months for rainfall and 2 months for rodent density indices was obtained for all areas. This is an important result in that if the model is used for making predictions of trap success in areas other than dunes, wadis, or at Karal, a lag of four months for rainfall and two months for rodent abundance index might be used if the researcher judges that conditions are similar to those in this study. Our lag of 4 months for rainfall, in general, agrees with Fiedler (1988) who noted that populations of the multimammate rat Praomys natalensis peaked 4 to 5 months after peak rainfall at several African sites.

Table 4 and Table 5 contain the final estimated models, standard errors, estimated residual variance, and R^2 values for predicting the two indices on rodent abundance: trap success ($\sqrt{(p*1000)}$ and density index ($-\ln(1-p)$). The models for trap success estimated for wadis, dunes, and Karal were not significantly different from one another and were combined to yield models which depend on rainfall and previous trap success only. The estimated models for predicting density index are slightly more complicated than the models for trap success in that models for wadis and Karal have significantly different coefficients than the models for dunes. For this and other reasons given below, the simpler model for predicting trap success is preferred. Note that some of the models have one or more coefficients which are not significantly different from zero ($\alpha=0.05$) due to the requirement that models for predicting indices for individual species abundance contain as a minimum the variables selected for prediction of total species abundance.

The remaining discussion on modeling indices of rodent abundance focuses on the (square root) trap success as the dependent variable of interest and its corresponding models, rather than density index. The reasoning behind this focus is based on four points: (1) square root trap success and density index yielded models with similar R^2 values (Table 4 and Table 5) and similar residual plots, (2) the square root transformation is known to be the variance stabilizing transformation of the Poisson distribution and is often found to yield transformed values of animal counts which are approximately normally distributed, (3) the theoretical basis of the density index transformation is unclear, and (4) square root trap success yielded

a simpler model than density index in that it appears to apply equally well to different sub-populations (species) and different sites. A model which can be applied to different sites is desirable because it is easier to use and with professional judgement can be regarded as a first approximation to indices on predicted size of populations other than the ones examined in this study. Figure 3, Figure 4, and Figure 5 illustrate the model for all species from Table 4. Observed trap success and predicted trap success (un-transformed) of all species are plotted for dunes, wadis, and Karal respectively using the model for all species and square root trap success. Note the change in scale on the vertical axis between Figure 4 and Figure 5.

Table 6 shows values of the inverse of the sum-of-squares and cross-product matrix ($(X'X)^{-1}$) which, along with model coefficients, are necessary to construct a prediction interval for a value of trap success at some point in the future using the models in Table 4. The only difference between predicting indices on wadis, dunes, and at Karal is that the independent variable of trap success in each of the models come from the area for which the prediction is sought. If the average trap success on all transects from both wadis and dunes is the same number, the models yield the same prediction. It is important to realize that it is not valid to use indices from wadis to predict indices on dunes. To predict trap success of all rodent species two months in advance after a trapping trip in the field, the scenario would be:

1. square root trap success times 1000 is averaged over all transects and sites (eg. wadis) visited to obtain the value of square root trap success for the current month;
2. rainfall (in mm) **two months prior** to the current month is averaged over all rainfall sites;
3. rainfall two months ago and square root trap success in the current month are substituted into the first equation in Table 4 to compute a point estimate of square root trap success **two months in the future.**
4. computations in Neter et al. (1985) are followed to construct a 95% prediction interval on the point estimate of trap success.

An example of computations appears in Table 6.

By recursive application of one model, it is possible to calculate tentative estimates for trap success four months into the future. Using current data on trap success and rainfall two months previous, trap success could be predicted two months in the future (described above). This estimate of trap success could then be treated as an "observed" trap success and, combined with rainfall in the current month, and substituted into the dependent portion of the model to extrapolate an estimate four months into the future. The upper and lower bounds of a confidence interval on this ad hoc estimate would not be known but the estimate could be updated when additional trapping data becomes available.

Model Adequateness

Following the description in the methods section, the model for square root trap success on all rodent species was used to predict square root trap success during hypothetical cycles in trap success. Figure 6 and Figure 7 present plots of hypothetical mean 10 day rainfall during a month, hypothetical trap success , and predicted trap success using the above model. In Figure 6 the hypothetical trapping success values are in the range of 90% of the observed data (note that approximately 10% of the observed data is lost because of lagging the explanatory variables) and show an increase four months after rain, a slight decline, and then an increase after rain in two subsequent years. Based on visual inspection, Figure 6 shows that the model provides adequate predictions when data are in the range of observed data used to construct the model. In Figure 7 the hypothetical trapping success values increase to approximately four times the maximum of the majority of observed data. Figure 7 shows that predictions increase when rodent abundance increases and decline when rodent abundance declines, but that the model has difficulty predicting the magnitude of indices outside the range of values used to construct it. Other hypothetical examples (not shown) indicate that the model works well when rodent populations truly lag behind rainfall by four months and less well when they do not. However, when rodent numbers truly lag behind rainfall by only two months the predictions may still be adequate. In other situations where

rainfall and rodent numbers were lagged by less than two and more than five months, the model predictions were inadequate.

Reduced Field Sampling Effort

Figure 8, Figure 9, and Figure 10 show contours on the surface of the ratio of SDS, sum of differences squared, produced by the reduced sampling effort to the SDS produced by the full sampling effort in the study. In the discussion which follows, we use the generic term field to refer to wadis. Quadratic interpolation was used to fit the surface and estimate contour lines through points which were not included in the simulation exercise (R^2 of the quadratic interpolation surface = 0.992). Figures labeled 110%, 125%, and 150% have points plotted which yield the indicated percent increase in SDS due to the reduced sampling effort (relative to the sampling effort realized in this study). The ratio of the square roots of SDS (i.e., ratios of the standard errors of predictions) are perhaps easier to interpret and are given by 105%, 112%, and 122% respectively for the 3 figures. For example, in Figure 9 any point on a line in the graph represents a sampling effort which is estimated to have $SDS^{1/2}$ which is approximately 112% of the $SDS^{1/2}$ for the observed data set. These figures can be used to balance the cost of increased sampling effort in each of the components (number of fields, number of transects/field, and number of recovered traps/transect) against the expected decrease in prediction variance relative to the present study. For example, with 6 fields, 4 transects/field, and approximately 11 recovered traps/transect one can expect an increase in prediction standard error of approximately 112% relative to the present study (Figure 9). On the other hand, if visiting additional fields is very expensive but deploying transects within a field and traps within a transect is not, one might expect an increase of approximately 122% in prediction standard error with 3 fields, 6 transects/field, and about 11 recovered traps/transect (Figure 10).

A general feature of these figures is that variance is increased as sampling effort is moved toward the lower left-hand corner corresponding to decreased effort. Numbers along the

"Traps/Transect" axis represent numbers of recovered traps per transect. In the observed data set, an average of roughly five to seven traps were lost for a variety of reasons. For future sampling efforts, an estimate of lost traps should be added to the numbers from the graphs to determine the number placed in the field.

Based on the models developed, prediction of rodent abundance is made two months in the future and does not depend on data more than two months old. Given the present data on rainfall, the rainy season appears to be roughly June through September in Chad. It would be desirable to examine longer term data records on rainfall to verify this observation. We assume that continuous rainfall records are available. The chronic annual increase in rodent population numbers (as measured by trapping success) is predicted to increase 4 months after the beginning of increased rainfall. The recommended months for sampling rodents is: June through September with no sampling during October through May unless rodent numbers and model predictions indicate that an "outbreak" is developing. Given rainfall from April and trap success from June, trapping success is estimated for August. Similarly, estimates can be obtained for September, October, and November based on four months of rodent sampling.

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All species combined

Site	Variable			
	Rain	NVDI	%Preg	√(p)
Karal	(9)	0	0,1	1
Wadis	4	2	(5)	1,2,3,4
Dunes	5,6,7	4,5	(6)	1,2

Gerbillus andersoni

Site	Variable			
	Rain	NVDI	%Preg	√(p)
Karal	3	2,3	ND	5
Wadis	4	4	ND	1,2
Dunes	5,6,7	4,5	ND	1,2

Arvicanthis niloticus

Site	Variable			
	Rain	NVDI	%Preg	√(p)
Wadis	4	2	ND	1,2,3,4

Mastomys spp.

Site	Variable			
	Rain	NVDI	%Preg	√(p)
Karal	1	0	ND	None

Table 1: Lags (in months) with significant correlation between trap success (square root transformed) and explanatory variables. Significant negative correlation denoted by (). "ND" is "Not Enough Data".

WADIS

Species	Trip 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Total
A. niloticus	170	77	21	8	10	3	6	2	5	4	2	4	2	2	.	1	2	2	.	3	6	2	332
G. andersoni	26	40	20	18	10	3	3	5	9	.	.	1	1	5	1	4	5	3	5	.	2	3	164
T. rob/T. lac.	26	21	10	2	4	.	.	.	1	.	1	.	1	1	.	2	2	1	1	.	.	2	75
J. jaculus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	1
Mastomys sp.	2	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	3
Unknown	9	4	2	.	.	1	3	4	5	3	.	.	.	.	.	.	.	.	1	.	.	.	32
All	233	142	53	28	24	7	12	11	20	7	3	6	4	8	2	7	9	6	7	3	8	7	607

DUNES

Species	Trip 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Total
G. andersoni	.	61	27	15	12	3	7	2	2	1	.	.	2	12	4	4	2	5	2	.	4	.	165
J. jaculus	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	1	.	.	1	.	3
T. rob/T. lac.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Unknown	.	.	.	.	1	1	.	1	2	.	.	.	.	.	.	.	.	.	.	.	.	.	5
All	NS	61	28	15	13	4	7	3	4	1	0	0	2	13	4	4	2	6	2	0	5	0	174

KARAL

Species	Trip 1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
A. niloticus	.	.	1	.	.	.	.	.	.	.	.	.	.	.	1
G. andersoni	.	4	3	7	.	.	1	.	1	.	.	.	.	.	16
Mastomys sp.	9	10	8	4	1	.	3	.	1	2	1	2	.	2	43
Mus sp.	3	1	1	3	1	.	.	.	.	3	1	.	.	1	14
T. rob/T. lac.	10	6	1	2	1	.	.	.	.	1	.	.	.	1	22

Table 2: Location of species caught during each trip. "." means "no catch". "NS" means "not sampled".

Abbreviation	Scientific Name	Common Name
A. niloticus	Arvicanthis niloticus	Nile Rat
G. andersoni	Gerbillus andersoni	Gerbil
Mastomys sp.	Mastomys sp. [Praomys sp.]	Multimammate Rat
Mus sp.	Mus sp.	Mice
J. jaculus	Jaculus jaculus	-
T. rob/T. lac.	Tatera robusta, and Taterillus lacustris	-

Table 3: Abbreviations, scientific names, and common names of rodents used in Table 2.

$$\sqrt{\text{TRAP SUCESS} * 1000}$$

All Species: $\sqrt{p} = 1.1483 + 0.0626\text{rain(L4)} + 0.4414\text{rats(L2)}$

A. niloticus: $\sqrt{p} = 0.4449^{*} + 0.0794\text{rain(L4)} + 0.4133\text{rats(L2)}$

G. andersoni: $\sqrt{p} = 0.6521 + 0.0169^{*}\text{rain(L4)} + 0.5077\text{rats(L2)}$

Mastomys sp.: -- No significant model --

Estimated Standard Errors and R^2:

	$se(\beta_{(rain)})$	$se(\beta_{(rats)})$	MSE	Err df	R^2
All species	0.0255	0.0621	1.9999	36	0.80
A. niloticus	0.0305	0.0714	0.8099	12	0.93
G. andersoni	0.0219	0.0622	1.4266	36	0.77

Table 4: Final estimated models for **√(trap success * 1000).** "(Lk)" means "lagged k months". R^2 calculated in original scale. * indicates coefficient not significantly different from zero.

-ln(1-P)

All Species

Dunes: di= 0.00305* + 0.000516rain(L4) + 0.2331rats(L2)

Wadis&Karal: di= 0.00305* + 0.000516rain(L4) + 0.3809rats(L2)

A. niloticus

Wadis: di=-0.00290* + 0.000755*rain(L4) + 0.3382rats(L2)

G. andersoni

Dunes: di= 0.00885 + 0.000038*rain(L4) + 0.1978rats(L2)

Wadis&Karal: di= 0.00077* + 0.000038*rain(L4) + 0.4422rats(L2)

Mastomys sp.

-- No significant model --

Estimated Standard Errors and R^2:

	$se(\beta_{(rain)})$	$se(\beta_{(rats)})$	MSE(x1000)	Err df	R^2
All species					
Dunes:	0.000263	0.0458	0.1899	36	0.81
Wadis&Karal:	0.000263	0.0356			
A. niloticus					
Wadis:	0.000453	0.0490	0.1617	12	0.87
G. andersoni					
Dunes:	0.000110	0.0213	0.0336	36	0.83
Wadis&Karal:	0.000110	0.1031			

Table 5: Final estimated models for **-ln(1-p)**. "(Lk)" means "lagged k months". R^2 calculated in original scale. * indicates coefficient not significantly different from zero.

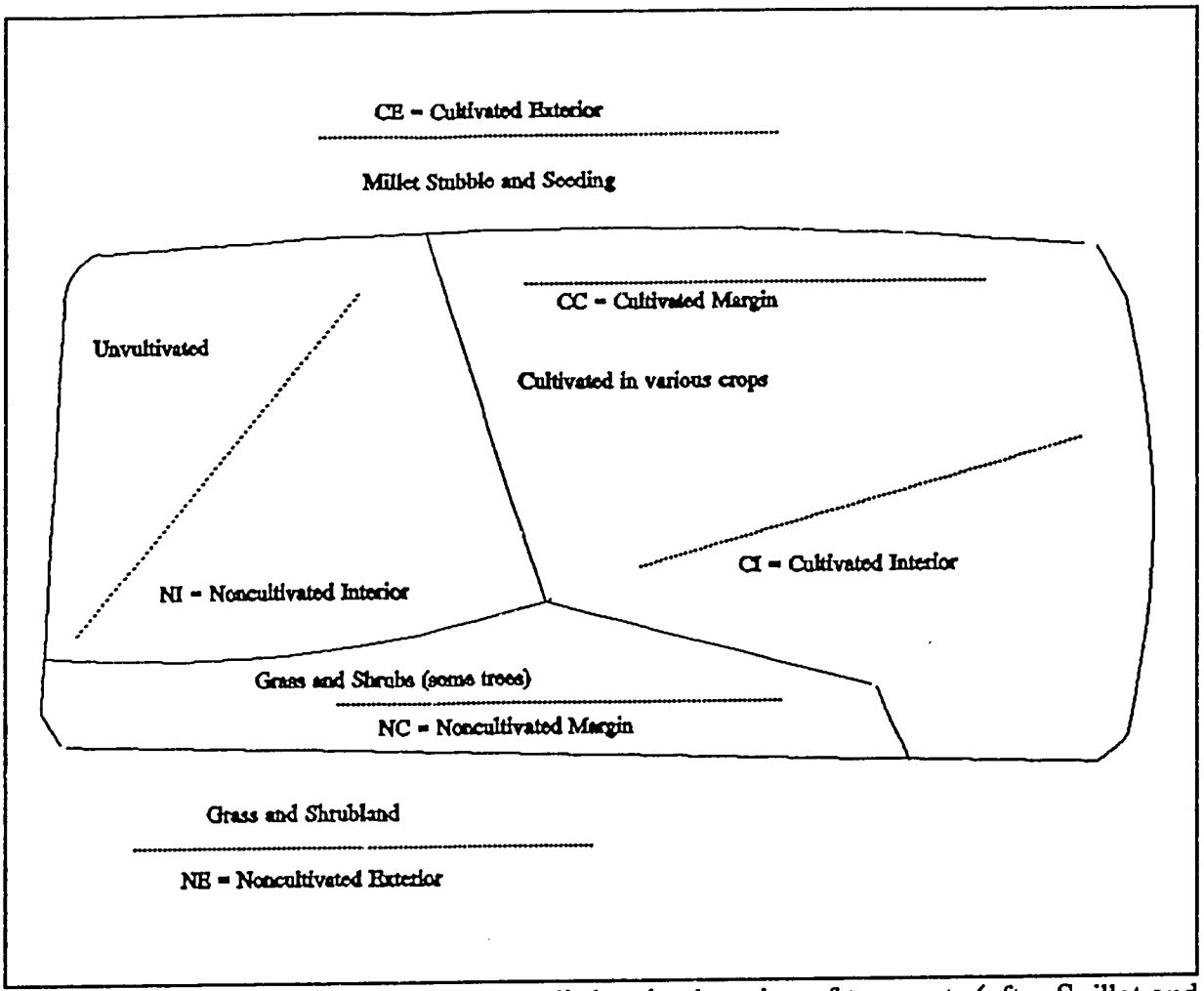

Figure 1: Schematic layout of typical wadi showing location of transects (after Spillet and Brooks (1991)).

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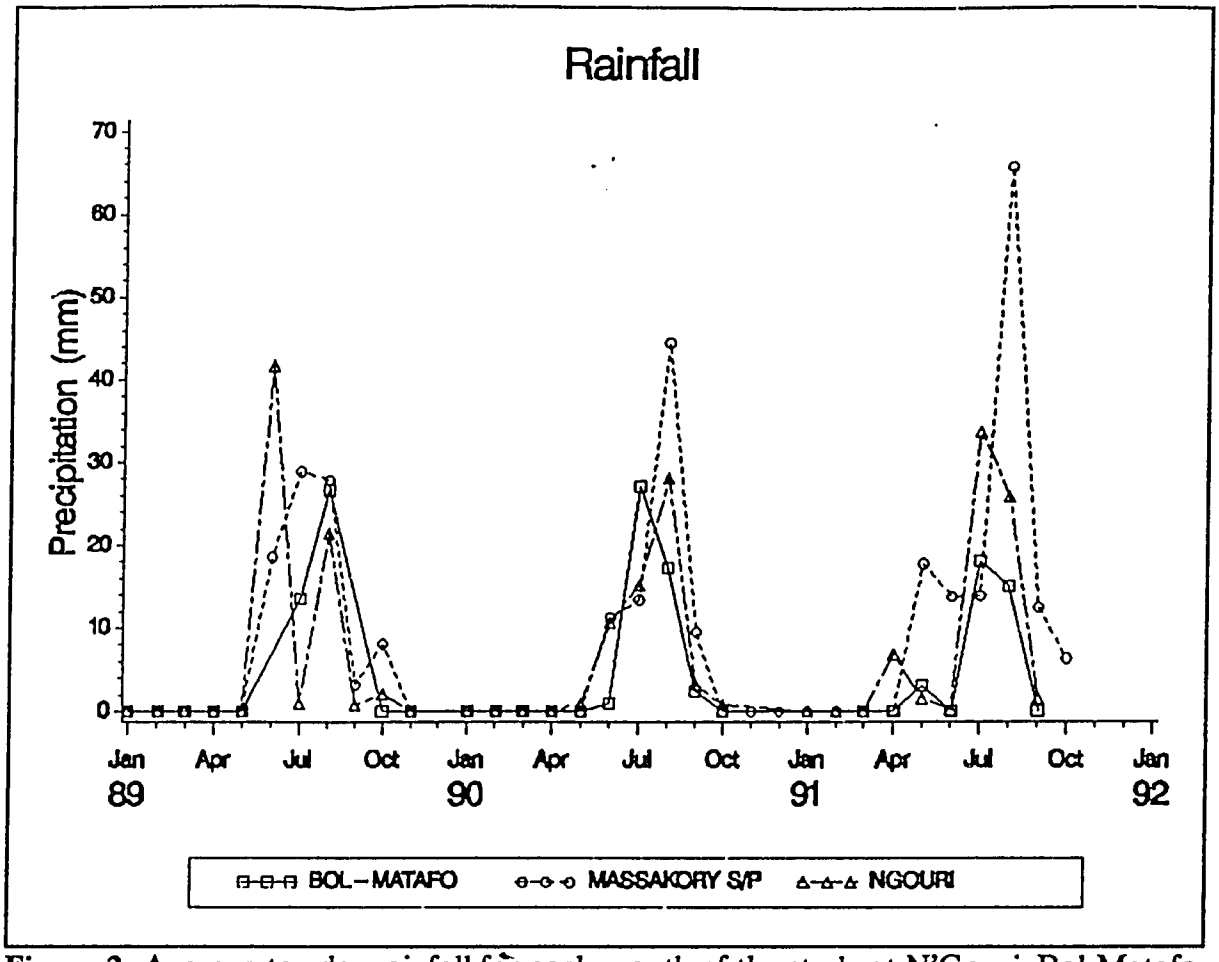

Figure 2: Average ten day rainfall for each month of the study at N'Gouri, Bol-Matafo, and Massakory S/P.

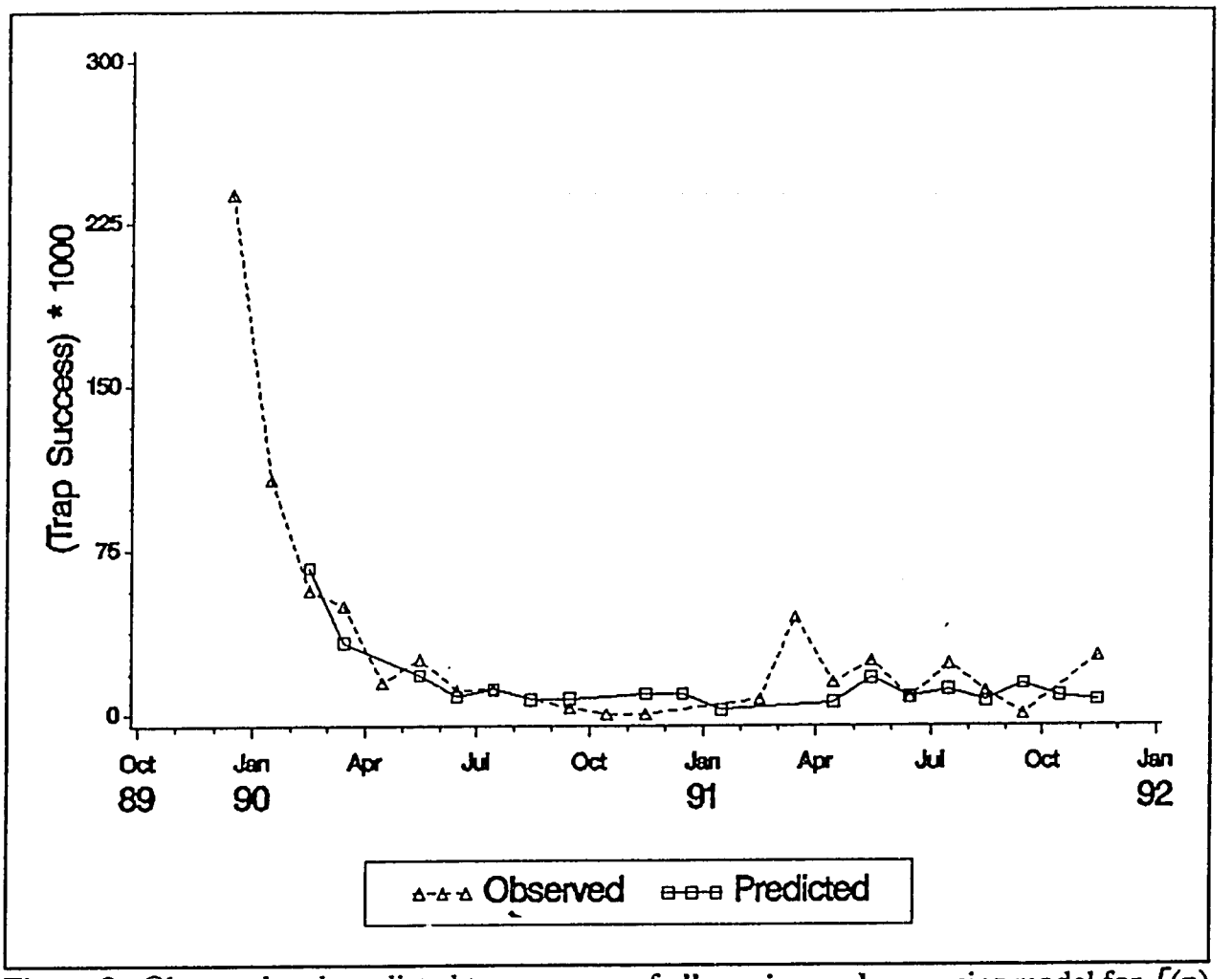

Figure 3: Observed and predicted trap success of **all species** on **dunes** using model for $\sqrt{(p)}$ at N'Gouri.

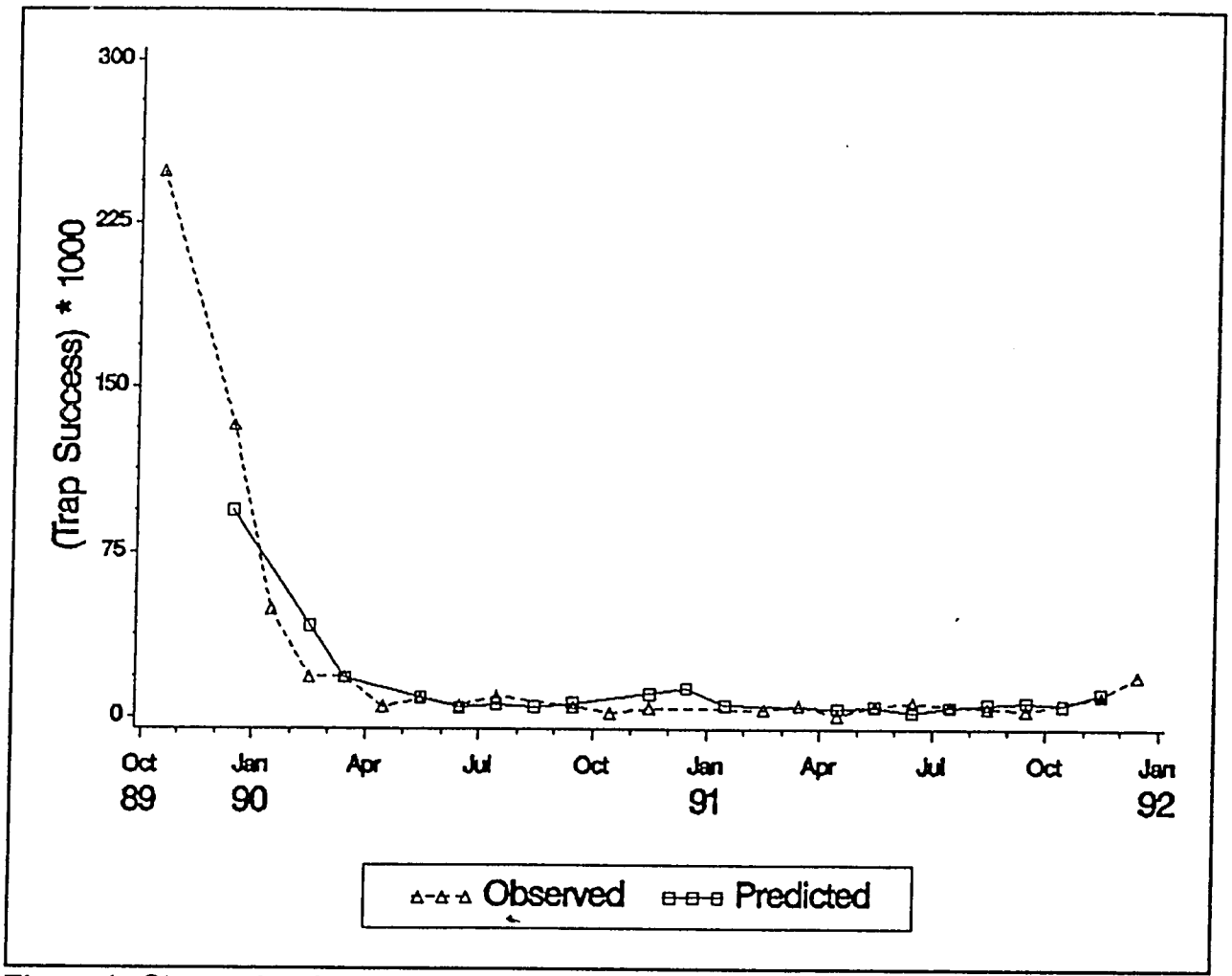

Figure 4: Observed and predicted trap success for **all species** on **wadis** using model for $\sqrt{(p)}$ at N'Gouri.

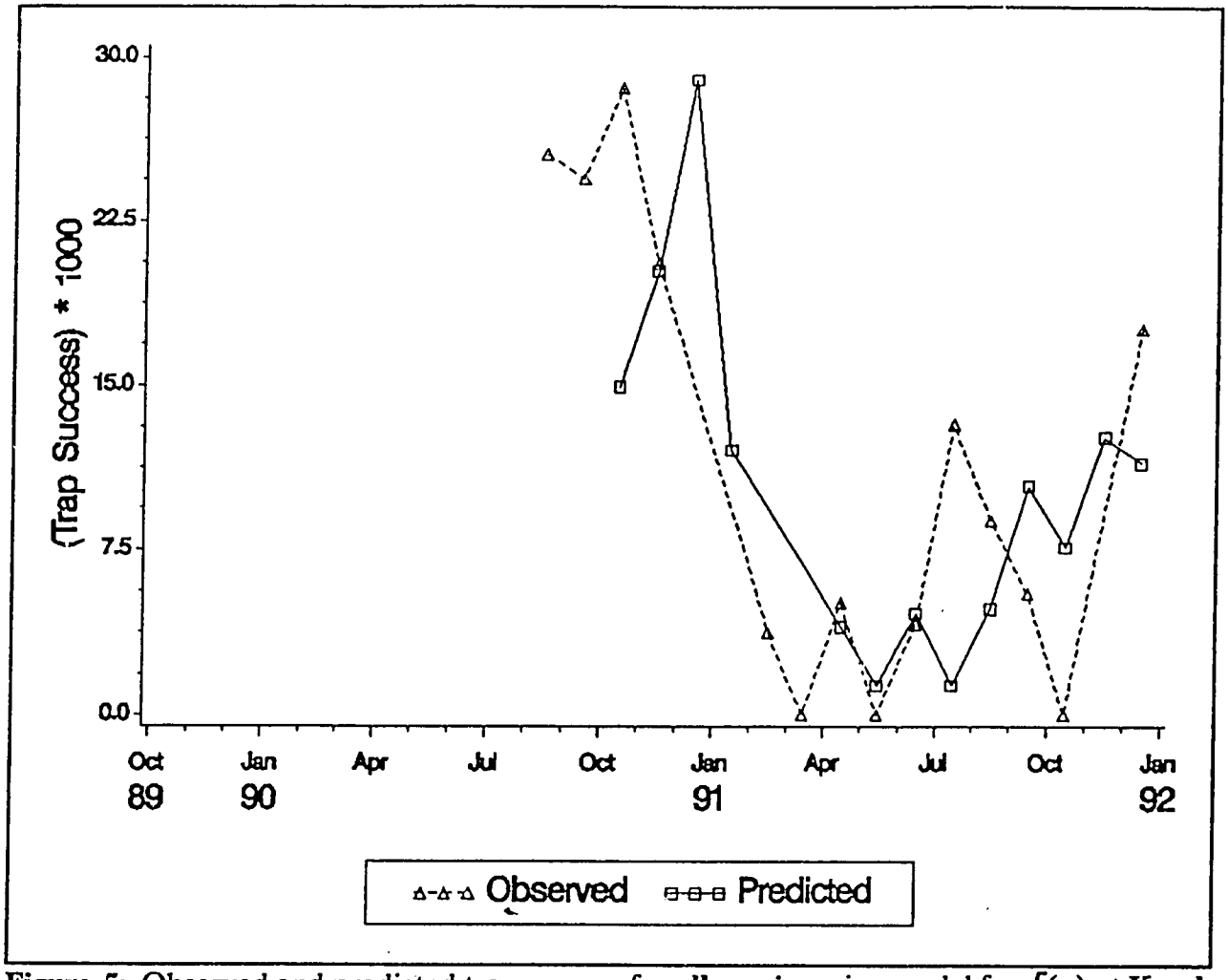

Figure 5: Observed and predicted trap success for **all species** using model for $\sqrt{(p)}$ at **Karal.**

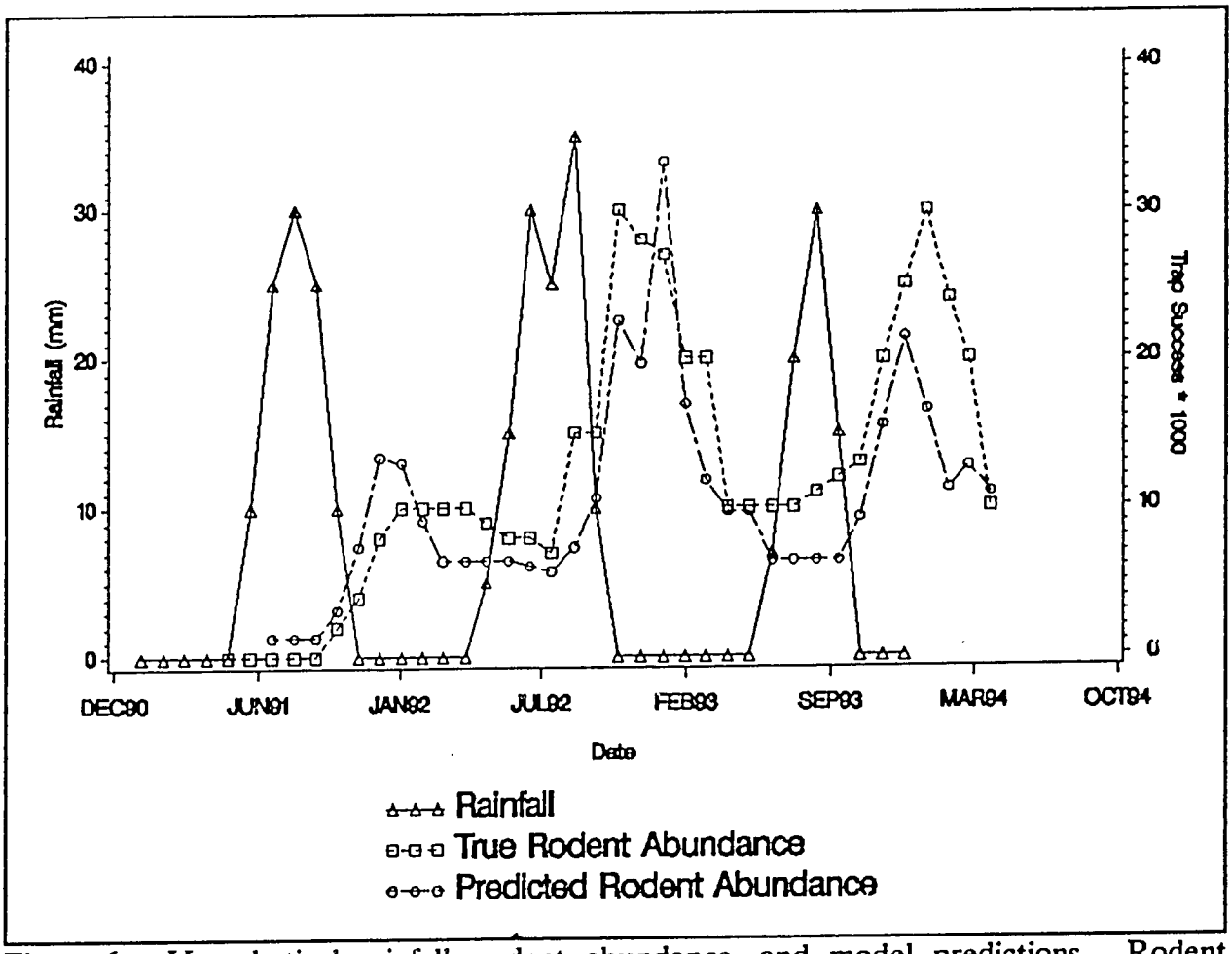

Figure 6: Hypothetical rainfall, rodent abundance, and model predictions. Rodent abundance is in the range of the data observed in the study.

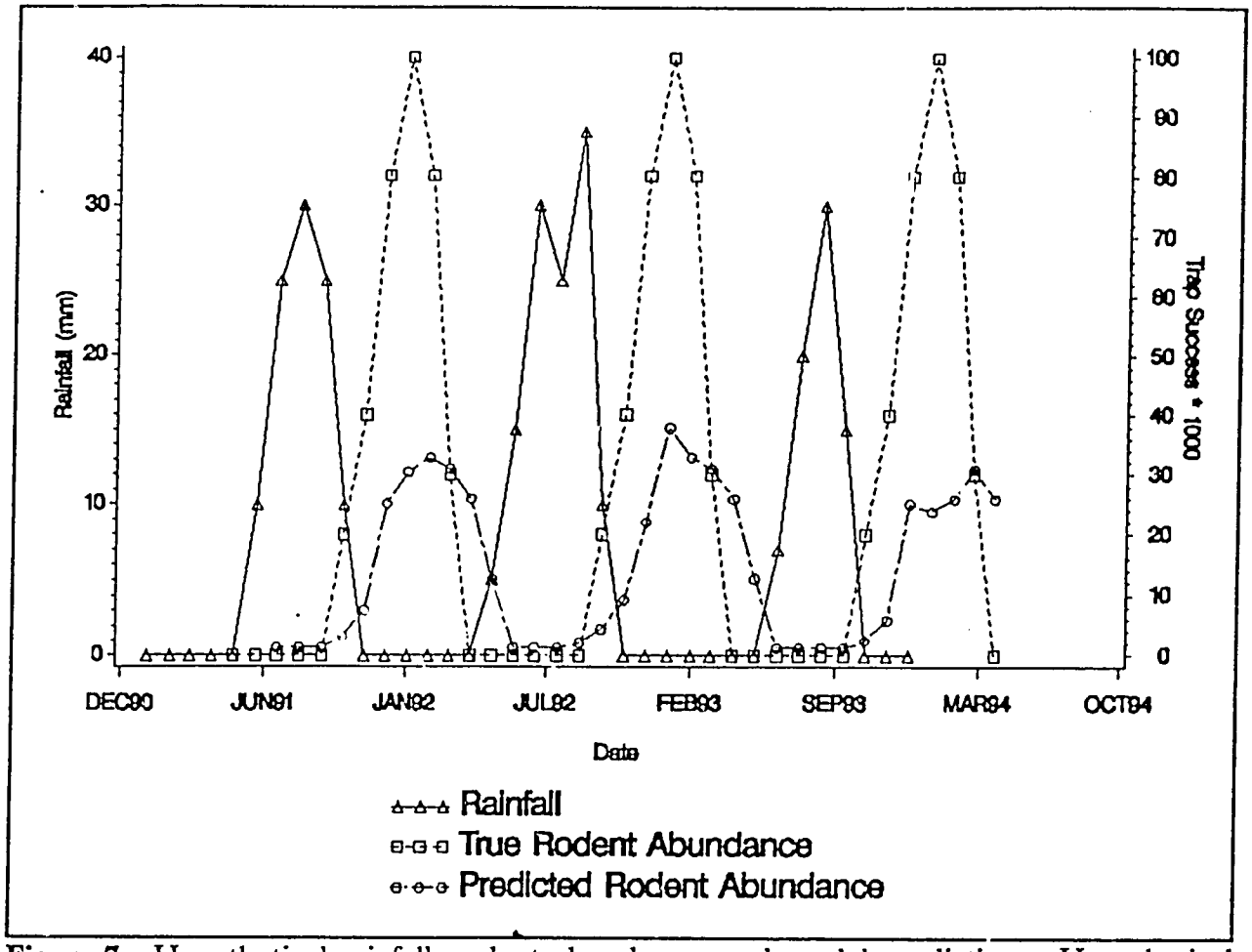

Figure 7: Hypothetical rainfall, rodent abundance, and model predictions. Hypothetical rodent abundence is outside the range of rodent abundence observed in the study.

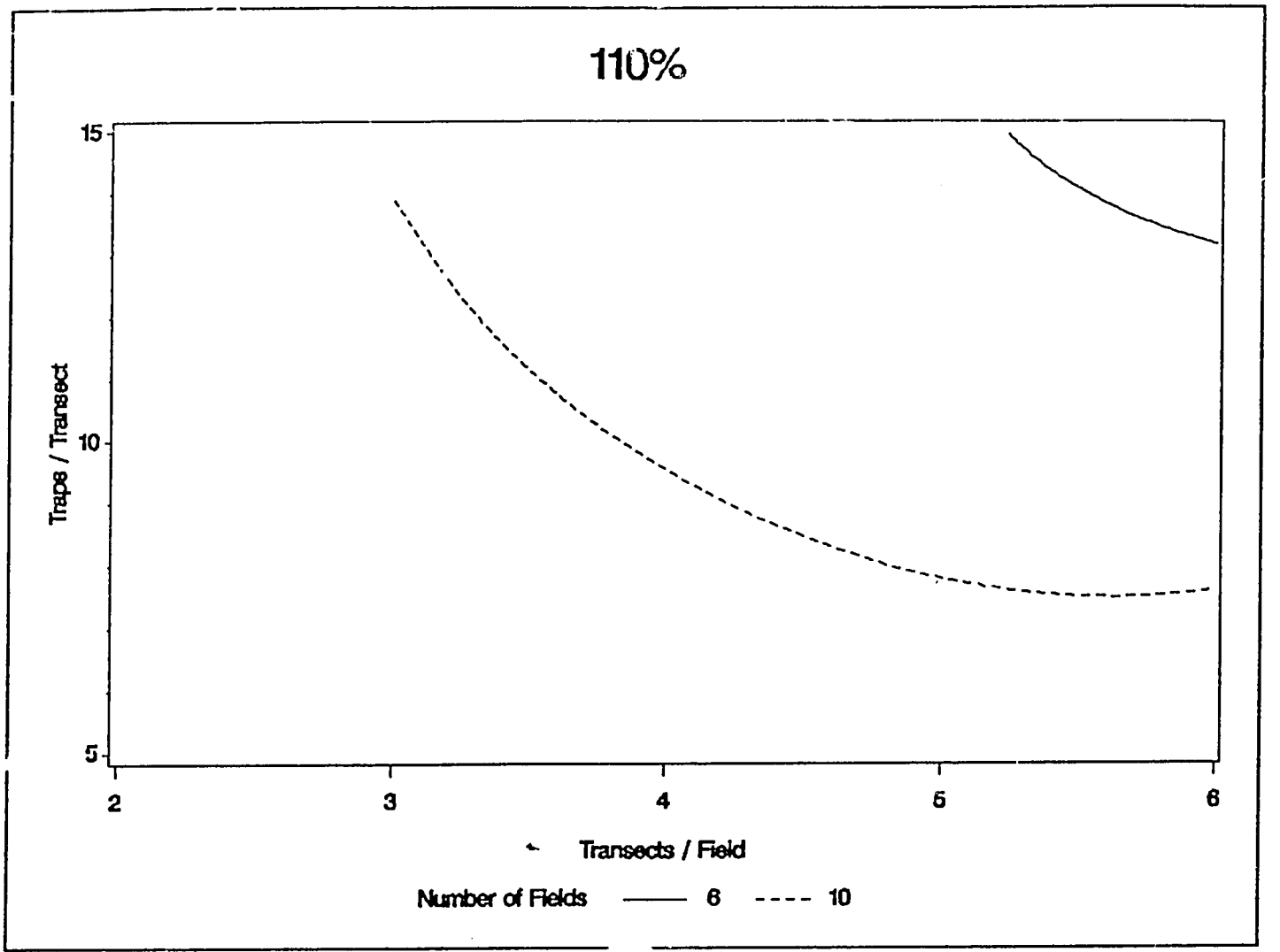

Figure 3: Contours determined by Monte Carlo . ulation and showing sampling schemes producing SDS error levels which were 110% of the observed 'SDS error level (ratio of standard errors = 105%).

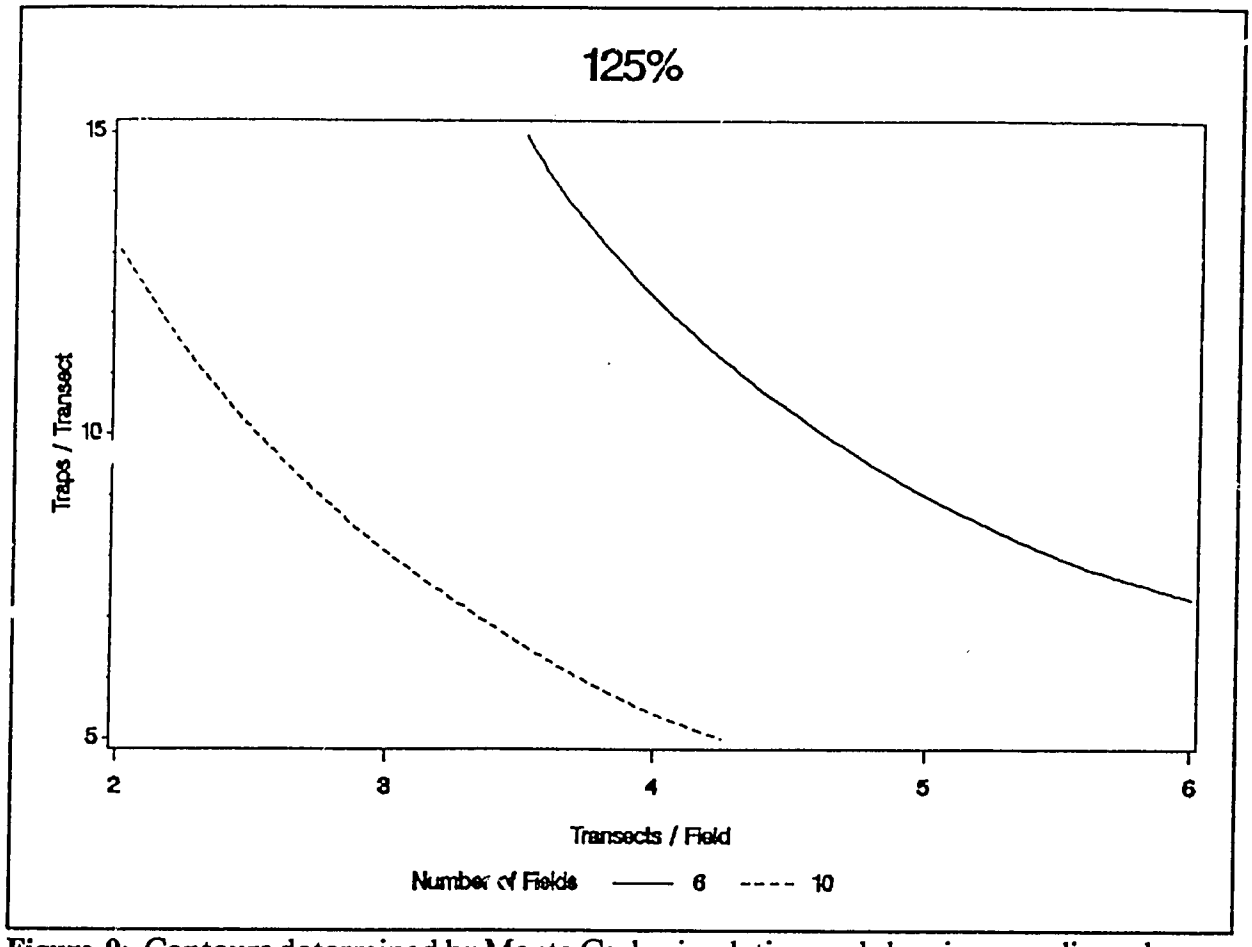

Figure 9: Contours determined by Monte Carlo simulation and showing sampling schemes producing SDS error levels which were 125% of the observed SDS error level (ratio of standard errors = 112%).

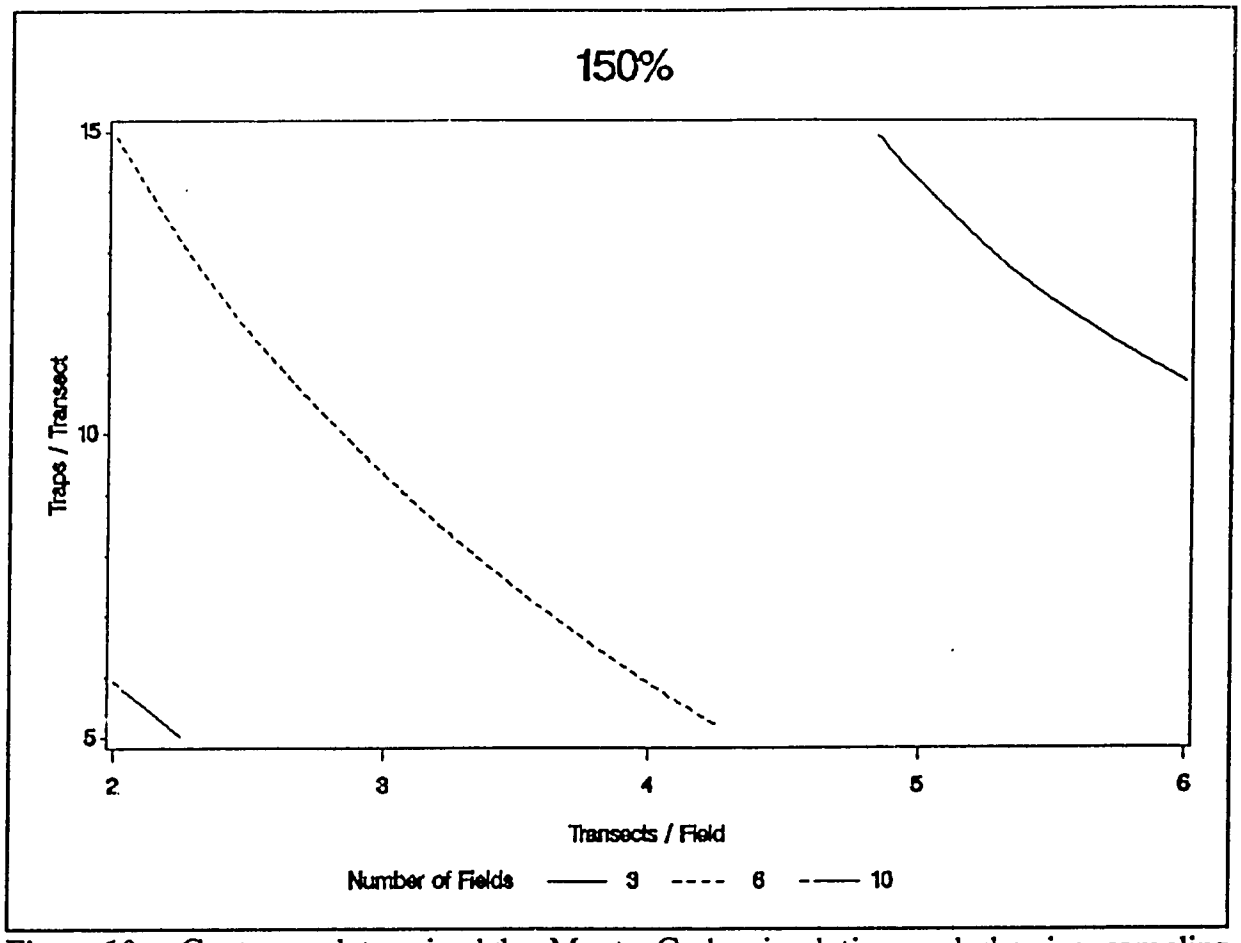

Figure 10: Contours determined by Monte Carlo simulation and showing sampling schemes producing SDS error levels which were 150% of the observed SDS error level (ratio of standard errors = 122%).