Analysis of deer mouse capture-recapture data from Anacapa, Santa Barbara, and San Miguel Islands

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Introduction

Long term monitoring of deer mice (*Peromyscus maniculatus* subsp.) has occurred at multiple sites on Anacapa Island, Santa Barbara Island, and San Miguel Island since 1992. Sites sampled on each island consisted of non-randomly placed permanent trapping grids, and were usually sampled during the spring and fall seasons. In a few cases summer and winter sampling also occurred. Mice at monitoring sites were sampled using capture-recapture methods, which allow for estimation of detection probabilities and bias-corrected density estimates. In this report I present density estimates for each site × season × year combination, and model and estimate temporal trends and average annual rates of change in density for these data alone and in aggregate.

Methods

Density estimation

Mice at each site were sampled using a rectangular trapping grid consisting of 49 to 100 live traps spaced at 7 m intervals, and were checked daily for 1 to 6 nights. Mice that were newly captured were provided with a unique identifying mark (ear tag or toe clipping), were sexed and weighed, and were released at the point of capture. For recaptured mice identifying marks were recorded and mice were released at the point of capture.

For each distinct mouse captured a capture history was constructed to indicate whether it was captured and released (1), captured and not released (-1), or not captured (0) on a particular occasion (day). Thus, a capture history of 1 0 -1 indicates the individual was captured on the first day of trapping, not captured on the second day, and was recaptured but not released (e.g., a mortality) on the third day. The set of capture histories for a particular site × season × year combination were combined to construct a capture history matrix of the following form:

0802.1	1	1	1	0	22.0
0813.1	1	1	1	0	21.0
0814.1	1	1	1	1	
0815.1	1	1	1	1	21.0
0816.1	1	0	0	0	26.0
0817.1	1	0	0		25.5
0818.1	1	-1	0	1	21.0
0820.1	0	1	1	0	15.5
0821.1	0	1	1	1	26.0
Escape	1	0	0		

In this example ten distinct individuals were captured. The first column represents the individual's unique id number, the second through fourth columns represent the capture history for that individual over the 3 days the trapping grid was run, the fifth column indicates sex (1 = male, 0 = female), and the sixth column is the weight of the individual in grams. Empty fields indicate missing values. In cases where an individual escaped or was released before it was marked (e.g., the last row in the capture history matrix above), the capture history was censored unless the capture occurred on the last occasion (hence, the last animal in this capture history matrix would be censored). For capture history matrices where fewer than 20% of the values for sex were missing, the proportion (p) of males in the capture history matrix was computed and the missing values were randomly assigned a value of 1 (male) with probability p, and 0 (female) with probability 1-p. For capture history matrices where less than 20% of the values for weight were missing, the average of the non-missing weight values was computed and the missing values were assigned that average weight. In cases where ≥ 20% of the values for sex (weight) were missing, I omitted covariate data for sex (weight) from the analysis.

I analyzed the capture-recapture data for each site × season × year combination using Huggins (1991) closed-population capture-recapture models to estimate capture probabilities. These models are maximum likelihood (and therefore have many desirable properties), they condition on captures so abundance (N) is not explicitly part of the likelihood function (which stabilizes the numerical optimization method used to estimate parameters), and detection probabilities can be explicitly modeled as a function of covariates such as sex and weight. Under these models abundance is estimated as a derived parameter (see Huggins 1991 for details).

I used Program MARK (White and Burnham 1999) to construct models and estimate detection probabilities and abundance for each of the approximately 190 capture history matrices in the mouse monitoring data set. The most general model I analyzed was additive and allowed for capture probabilities (p) and recapture probabilities (c) to vary across capture occasions (time) and among individuals as a function of sex and weight. I also analyzed all possible subsets of this model where p and c were not constrained to be equal, which for 3 capture occasions (the most common number of days a grid was run) yielded a total of 32 models. I then constrained $p = c$ and constructed all possible subsets of an additive time, sex, and weight model, which for 3 capture occasions yielded a total of 16 models. Thus, in the typical case where there were 3 capture occasions, a total of 48 models were constructed and their parameters estimated.

Once all models had been run they were ranked by their AIC_c values (from lowest to highest, where lower values indicate a better model), and the weights for the ith model (w_i) were computed (Burnham and Anderson 2002). These weights are the Bayesian posterior model probabilities (thus the weights sum to 1), and represent the probability that model i is the Kullback-Leibler best model (Burnham and Anderson 2002). Unfortunately, in many cases data were sparse and the results for many of the models (including some of the top AIC_c models) indicated the numerical optimization routine failed to converge on reasonable values and the model should be deleted from consideration. Therefore, for all models with $w_i \geq 0.01$ I screened the output and deleted models that I judged inappropriate. In general, I deleted models meeting one or more of the following criteria:

1. One or more of the parameters were singular.

2. The lower and upper bounds on the confidence interval for p (or c) were near 0 and 1, respectively.
3. The estimated abundance or standard error were unrealistically large, or the standard error equaled 0.
4. The coefficient of variation on a parameter was unrealistically large.

I also deleted models with $w_i < 0.01$ because the weights were so small they indicated there was little support for such models.

Once inappropriate models were deleted, I model-averaged the remaining models to obtain a model-averaged estimate of abundance and its unconditional standard error (Burnham and Anderson 2002). Program MARK does this computation automatically.

In 3 data sets the number of distinct animals captured on a grid was 0 or 1, so abundance was not estimable under the Huggins (1991) models and therefore was set to 0 or 1, as appropriate. In two cases every animal captured on the grid was found dead in the trap and there were no recaptures, so abundance was not estimable under the Huggins (1991) models and was set to the number of distinct animals captured. In none of these cases could I estimate a standard error, so it was set to 0.

I estimated density ($\hat{D}$) as $\hat{N} / \hat{A}(\hat{W})$, where $\hat{N}$ is estimated abundance and $\hat{A}(\hat{W})$ is the estimated area sampled by the trapping grid, which depends on an estimated buffer strip around the grid of width $\hat{W}$. Following Parmenter et al. (2003), and generalizing for rectangular (as opposed to square) grids, I let $\hat{A}(\hat{W}) = L_1 L_2 + 2L_1\hat{W} + 2L_2\hat{W} + \pi\hat{W}^2$, where L_1 and L_2 are the lengths of the longer and shorter sides of the rectangle formed by the trapping grid, and the buffer strip W was estimated using the mean maximum distance moved (MMDM) by mice trapped at least twice on the grid (see the formula for MMDM below). In previous studies MMDM was found to perform well for estimating W (Parmenter et al. 2003). In cases where fewer than two mice were captured twice, I set $W = 0$ and therefore $A(W) = L_1 L_2$.

An estimator for the variance of $\hat{D}$, $\hat{V}(\hat{D})$, was derived using Goodman's formula for the product of independent random variables (with estimated sampling variances) and yielded the formula:
$\hat{V}(\hat{D}) = \hat{N}^2\hat{V}(\hat{A}^{-1}(\hat{W})) + [\hat{A}^{-1}(\hat{W})]^2\hat{V}(\hat{N}) - \hat{V}(\hat{N})\hat{V}(\hat{A}^{-1}(\hat{W}))$, where $\hat{V}(\hat{N})$ is output by program MARK and by the delta method (Seber 1982) $\hat{V}(\hat{A}^{-1}(\hat{W})) = \dfrac{\hat{V}(\hat{A}(\hat{W}))}{\hat{A}(\hat{W})^2}$. Once again applying the delta method, we get $\hat{V}(\hat{A}(\hat{W})) = (2L_1 + 2L_2 + 2\pi\hat{W})^2\hat{V}(\hat{W})$, where $\hat{V}(\hat{W}) = \dfrac{\sum_{i=1}^{n}(d_i - \bar{d})^2}{n(n-1)}$. In this latter formula n = the number of mice captured at least twice ($n > 1$), d_i = the maximum distance moved by the ith mouse, and $\bar{d}$ = MMDM = $\frac{1}{n}\sum_{i=1}^{n} d_i$. In cases where $n < 2$, $\hat{V}(\hat{D}) = \left(\dfrac{1}{L_1 L_2}\right)^2 \hat{V}(\hat{N})$. I computed $SE(\hat{D})$ as $\sqrt{\hat{V}(\hat{D})}$.

I computed 95% CIs using the approach described by Burnham et al. (1987:211-213). For abundance, $\hat{N}$, the lower and upper bounds were computed as: [$M_{t+1} + f_0$/C,

$M_{t+1} + f_0 \cdot C$,], where M_{t+1} = the number of distinct mice captured on the grid, $f_0 = \hat{N}$ - M_{t+1}, and $C = \exp\left(1.96\sqrt{\log\left[1+\frac{\hat{V}(\hat{N})}{f_0^{\,2}}\right]}\right)$. For density, $\hat{D}$, the lower and upper bounds were computed as: $\left[\frac{M_{t+1}}{\hat{A}(\hat{W})}+\frac{f_0}{C}, \frac{M_{t+1}}{\hat{A}(\hat{W})}+f_0\cdot C\right]$, where $f_0 = \hat{D} - \frac{M_{t+1}}{\hat{A}(\hat{W})}$ and $C = \exp\left(1.96\sqrt{\log\left[1+\frac{\hat{V}(\hat{D})}{f_0^{\,2}}\right]}\right)$.

Trend estimation

I evaluated density data for trends using a generalized linear models approach that assumed a normal distribution and identity link function. I log (base *e*) transformed density data before analysis, and weighted observations in the analysis with weights equal to $1/V[\log(D)]$, where by the delta method (Seber 1982) $V[\log(D)] = V(D)/D^2$. I assessed normality and homogeneity of variances of residuals by constructing stem-and-leaf plots and normal probability plots, and I tested for normality using the Shapiro-Wilk statistic (Shapiro and Wilk, 1965). I modeled temporal trends separately for each grid × season combination (where there were sufficient data), then pooled data across grids on the same island (except for Anacapa Island) for island × season analyses.

For the grid × season analyses the most general model I considered included the variables: jday, year, and year^2. For the island × season analysis the most general model I considered was: jday, location_code, year, location_code × year, and year^2. In these models jday is the Julian day within the year (this was used to accommodate phenology in years where trapping was earlier or later than usual) and location_code was a categorical variable identifying the grid. All subsets of these models, under the constraint that year appeared in every model, were considered. I did not consider autoregressive models with lag terms for year due to the large number of years that were skipped within a given season, resulting in missing data for predicting abundance in the subsequent year. Typically analytical software censors observations with missing data and could lead to serious biases. The model with the lowest AIC_c was considered the model best supported by the data, and was used for subsequent inferences.

For Anacapa Island data for the East and West Islets were too sparse for a regression analysis. Consequently, I instead used linear contrasts (Ott 1988) to test specific hypotheses regarding time trends in the data. For the East Islet in the fall I tested the null hypothesis that density in 1997 was equal to the average of the 2010 and 2011 densities; for the East Islet in the Spring I tested the null hypothesis that density in 1998 was equal to the average of the 2010 and 2011 densities. For the West Islet in the fall I tested the null hypothesis that density in 1995 was equal to the density in 1996; for the West Islet in the Spring I tested the null hypothesis that density in 1993 was equal density in 1995.

When there were sufficient data for a regression analysis, I reported average annual rates of change in density (over a period of *t* years) as a percentage calculated as 100(λ-1), where the average of the finite rate of population change $\lambda = (D_t/D_0)^{1/t}$, D_t is the

predicted density (based on the best AIC_c model) in year t, and D_0 is the *predicted* density during the initial year (usually the first year of the survey).

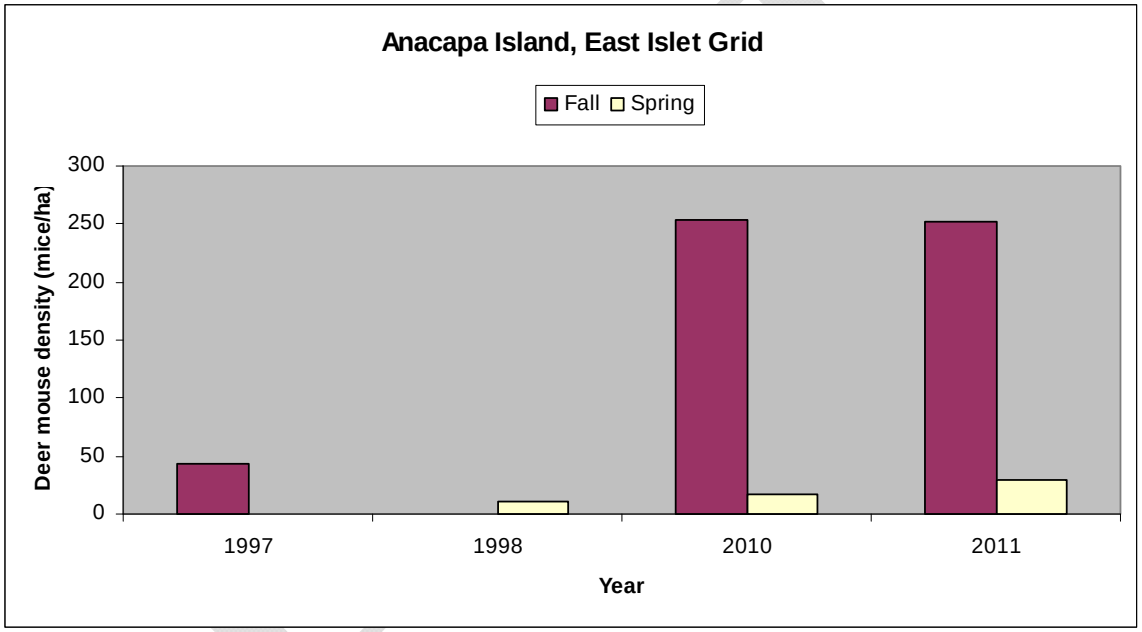
Results

Tables providing deer mouse density estimates by island, grid, and trapping date are in Appendix A. Annual density estimates and trend models (where possible) for spring and fall, by grid, are in figures 1-18 below.

Anacapa Island:

For Anacapa Island, the East Islet Grid data were insufficient for regression analysis (Figure 1). However, a *z*-test (two-tailed) comparing fall of 1997 with the fall of 2010 and 2011 indicated that densities were higher in 2010 and 2011 ($p < 0.001$). Likewise, a *z*-test (two-tailed) comparing spring of 1998 with the spring of 2010 and 2011 indicated that densities were higher in 2010 and 2011 ($p = 0.032$).

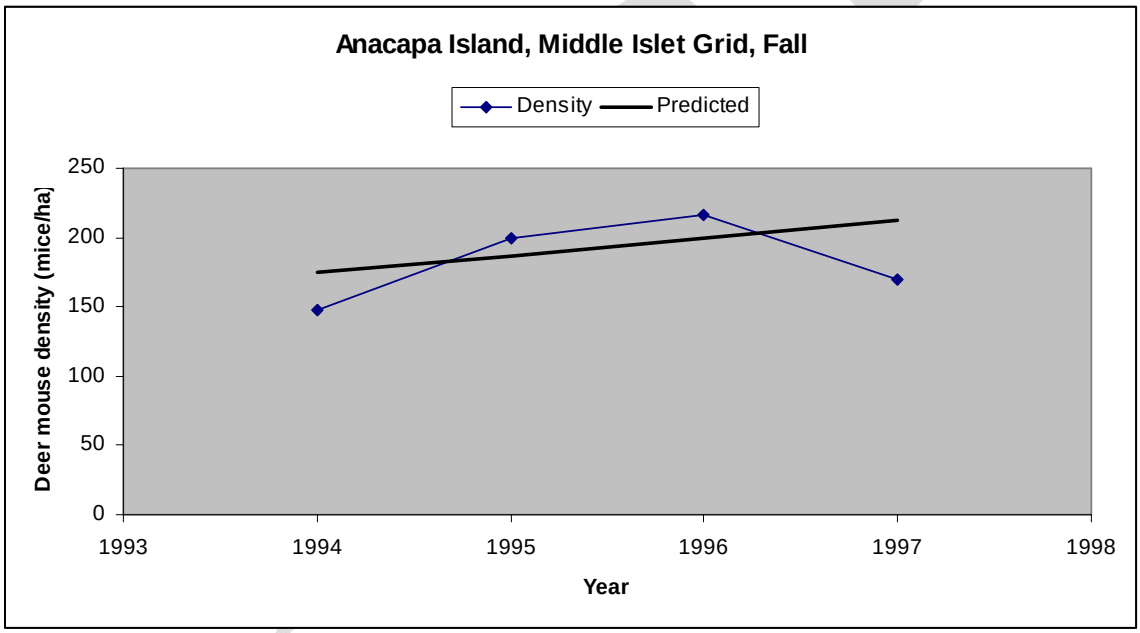
Figure 1. Annual deer mouse density estimates for Anacapa Island, East Islet Grid.



For Anacapa Island, the Middle Islet Grid data were sufficient to run a year only regression model but not more complex models. For the fall data (Figure 2) the estimated time trend was positive (the average annual rate of change was 6.7%) with a 95% confidence interval that covered zero, hence the trend parameter was not statistically different from zero:

Parameter	DF	Estimate	Standard Error	Likelihood Ratio 95% Confidence Limits	
Intercept	1	-124.885	157.1242	-523.949	274.1793
year	1	0.0652	0.0787	-0.1347	0.2652
Scale	1	1.1012	0.3893	0.6267	2.7005

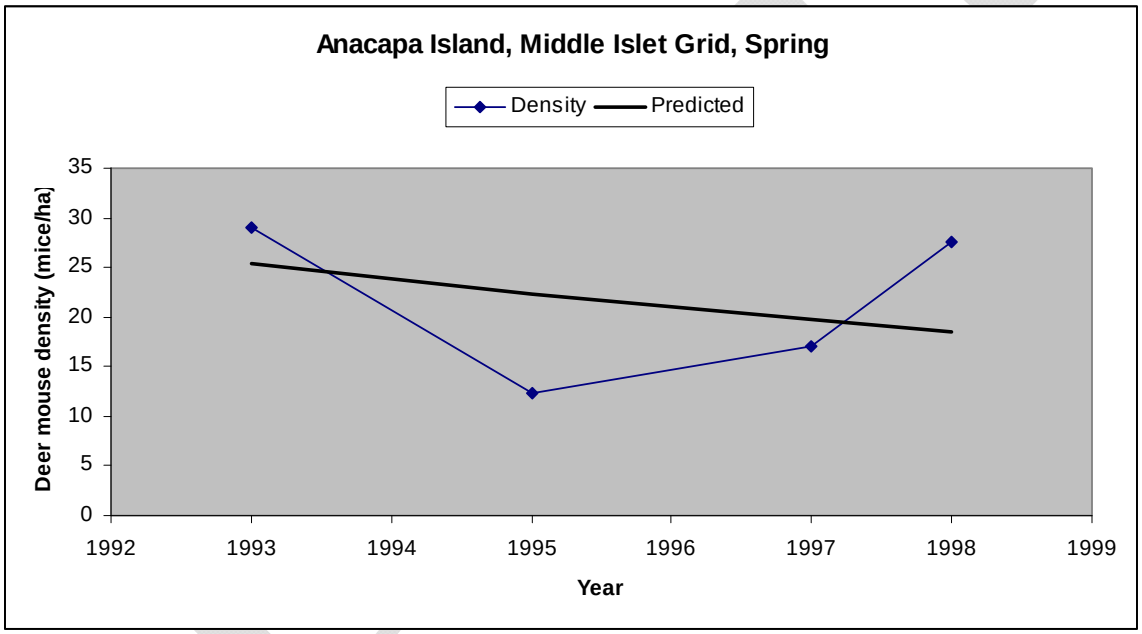
Figure 2. Annual deer mouse density estimates for Anacapa Island, Middle Islet Grid, during the fall.



For the spring data (Figure 3) the estimated time trend was negative (the average annual rate of change was -6.1%) with a 95% confidence interval that covered zero, hence the trend parameter was not statistically different from zero:

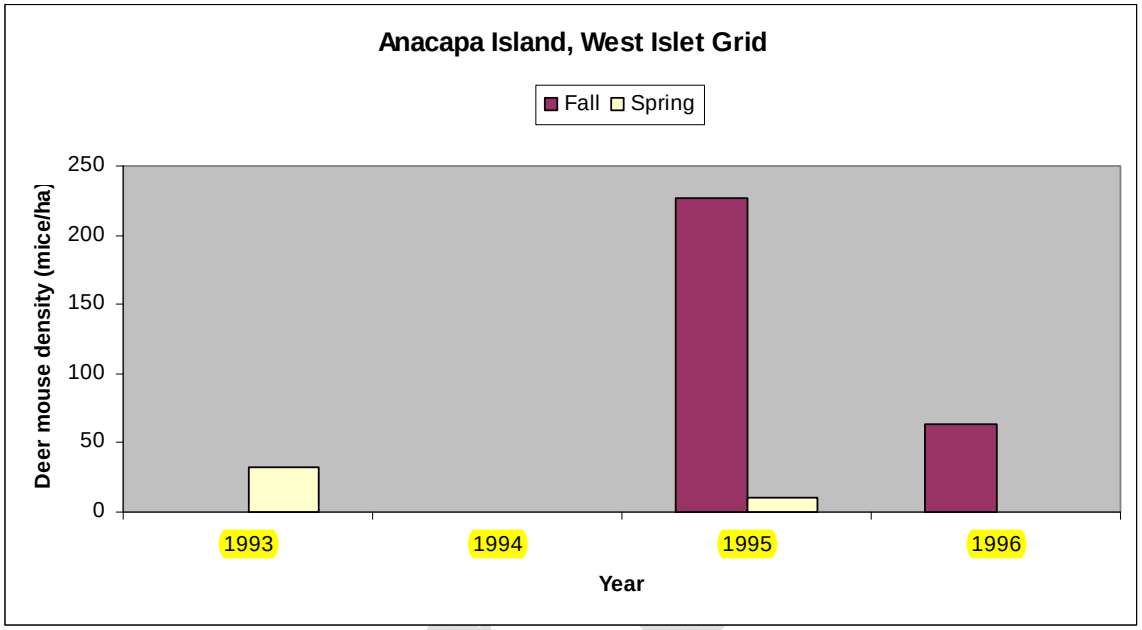
Parameter	DF	Estimate	Standard Error	Likelihood Ratio 95% Confidence Limits	
Intercept	1	129.4935	168.8701	-299.403	558.3902
year	1	-0.0634	0.0847	-0.2784	0.1517
Scale	1	1.3531	0.4784	0.7700	3.3183

Figure 3. Annual deer mouse density estimates for Anacapa Island, Middle Islet Grid, during the spring.



For Anacapa Island, the West Islet Grid data were insufficient for regression analysis (Figure 4). However, a *z*-test (two-tailed) comparing fall of 1995 with the fall of 1996 indicated that densities were higher in 1995 ($p < 0.001$). A *z*-test (two-tailed) comparing spring of 1993 with the spring of 1995 indicated that densities did not differ ($p = 0.426$).

Figure 4. Annual deer mouse density estimates for Anacapa Island, West Islet Grid.

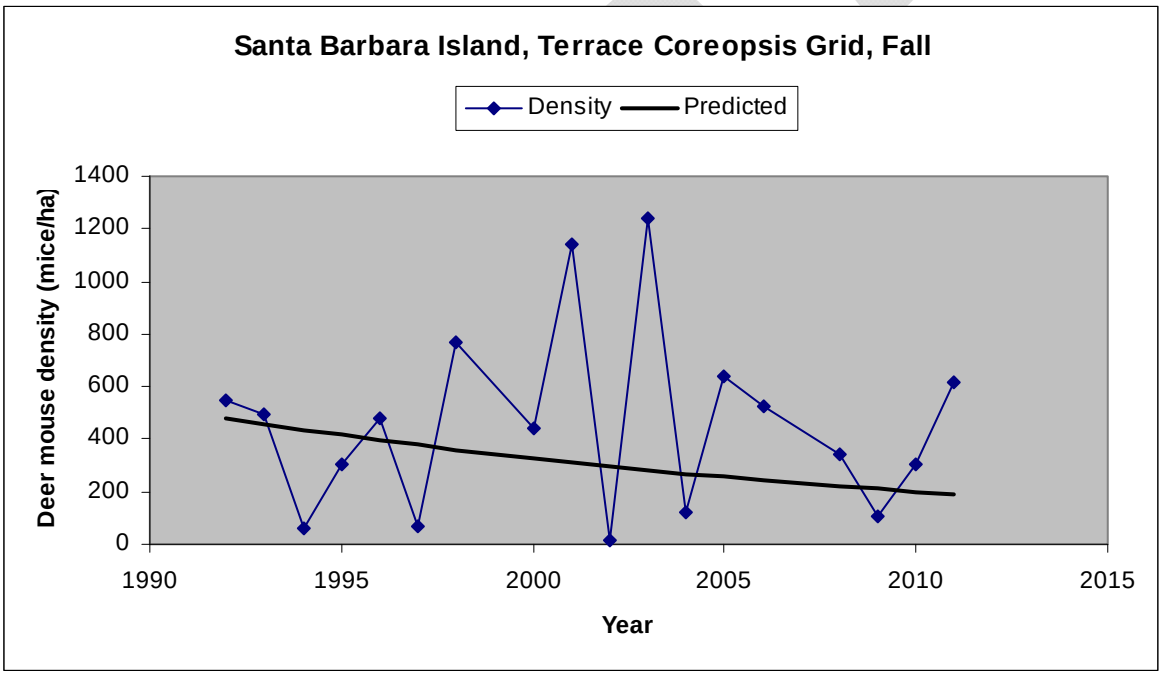


Santa Barbara Island:

For Santa Barbara Island, the Terrace Coreopsis Grid in the fall, the best model from those considered was a year only model. For these data (Figure 5) the trend was negative (the average annual rate of change was -4.7%) with the 95% confidence interval barely covering zero at the upper bound, hence while suggestive of a trend the trend parameter was not statistically different from zero:

Parameter	DF	Estimate	Standard Error	Likelihood Ratio 95% Confidence Limits	
Intercept	1	102.2706	53.5004	-8.4374	212.9785
year	1	-0.0482	0.0267	-0.1035	0.0070
Scale	1	6.7561	1.1260	5.0319	9.7464

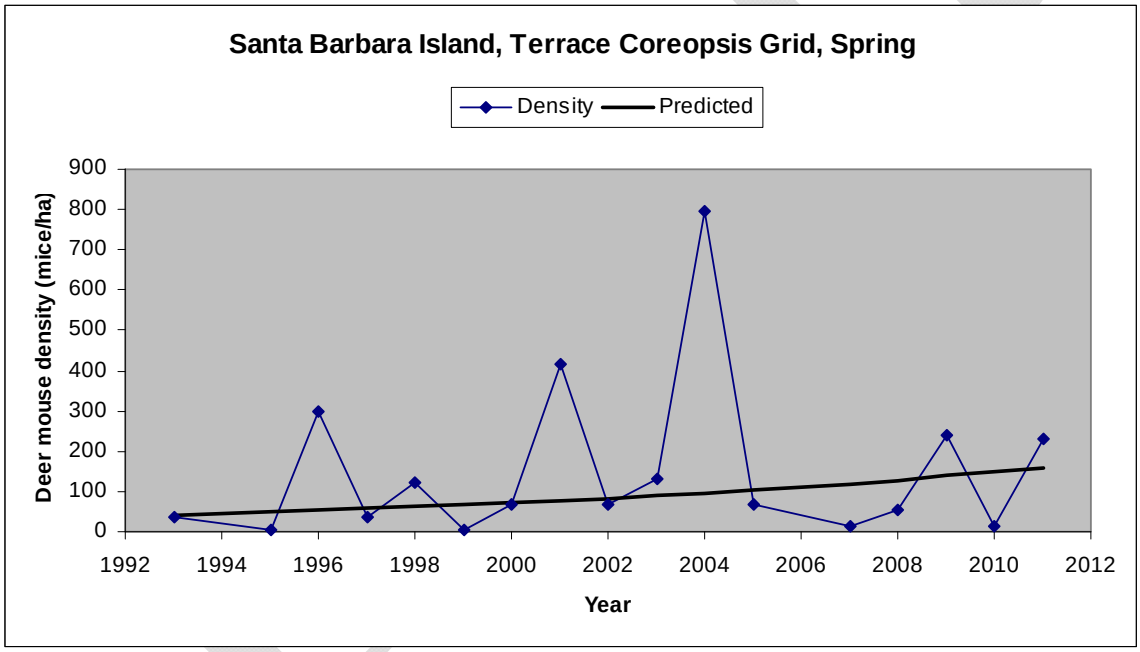
Figure 5. Annual deer mouse density estimates for Santa Barbara Island, Terrace Coreopsis Grid, during the fall.



For Santa Barbara Island, the Terrace Coreopsis Grid in the spring, the best model from those considered was a year only model. For these data (Figure 6) the trend was positive (the average annual rate of change was 7.6%) with the 95% confidence interval covering zero, hence the trend parameter was not statistically different from zero:

Parameter	DF	Estimate	Standard Error	Likelihood Ratio 95% Confidence Limits	
Intercept	1	-142.843	91.9956	-334.535	48.8489
year	1	0.0736	0.0460	-0.0223	0.1694
Scale	1	7.0820	1.2519	5.1907	10.4762

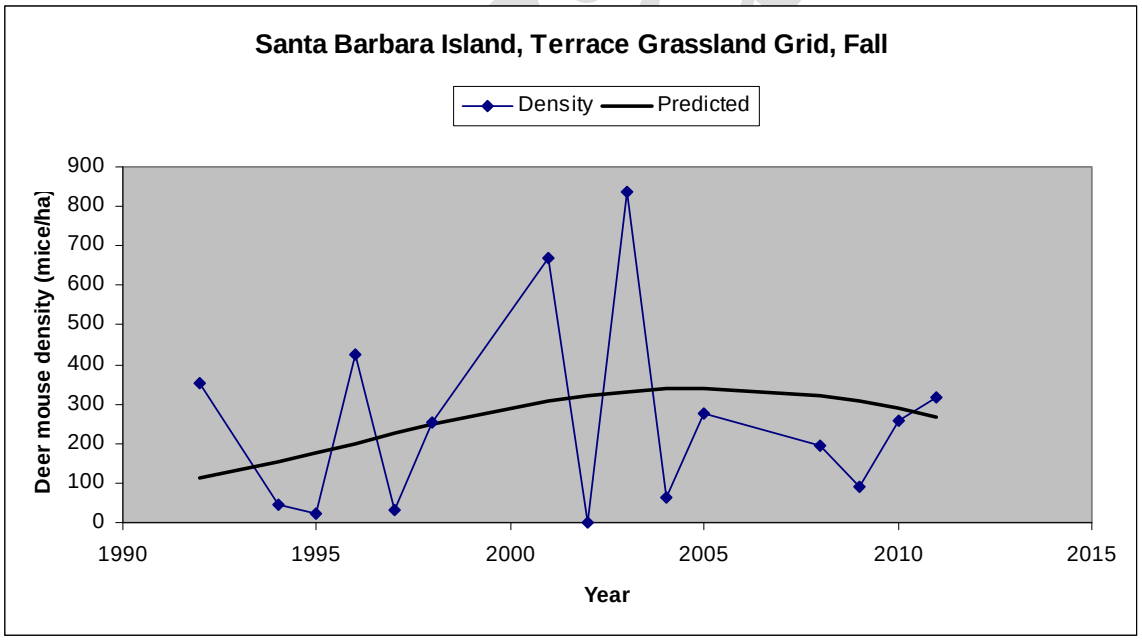
Figure 6. Annual deer mouse density estimates for Santa Barbara Island, Terrace Coreopsis Grid, during the spring.



For Santa Barbara Island, the Terrace Grassland Grid in the fall, the best model from those considered included the variables jday, year, and year^2. For these data (Figure 7) the predicted values suggest densities increased (the average annual rate of change was 8.8%) from 1992 to a peak in 2005, then declined (the average annual rate of change was -3.8%) from 2005 to 2011. For jday, year, and year^2 the 95% confidence intervals do not cover zero, indicating these parameters statistically differ from zero (before analysis years were rescaled from 1-20, with 1 = 1992 and 20 = 2011):

Parameter	DF	Estimate	Standard Error	Likelihood Ratio 95% Confidence Limits	
Intercept	1	15.7488	1.9525	11.6438	19.8537
jday	1	-0.0380	0.0073	-0.0535	-0.0226
year	1	0.1820	0.0531	0.0704	0.2937
year*year	1	-0.0065	0.0025	-0.0118	-0.0013
Scale	1	1.8301	0.3458	1.3160	2.7919

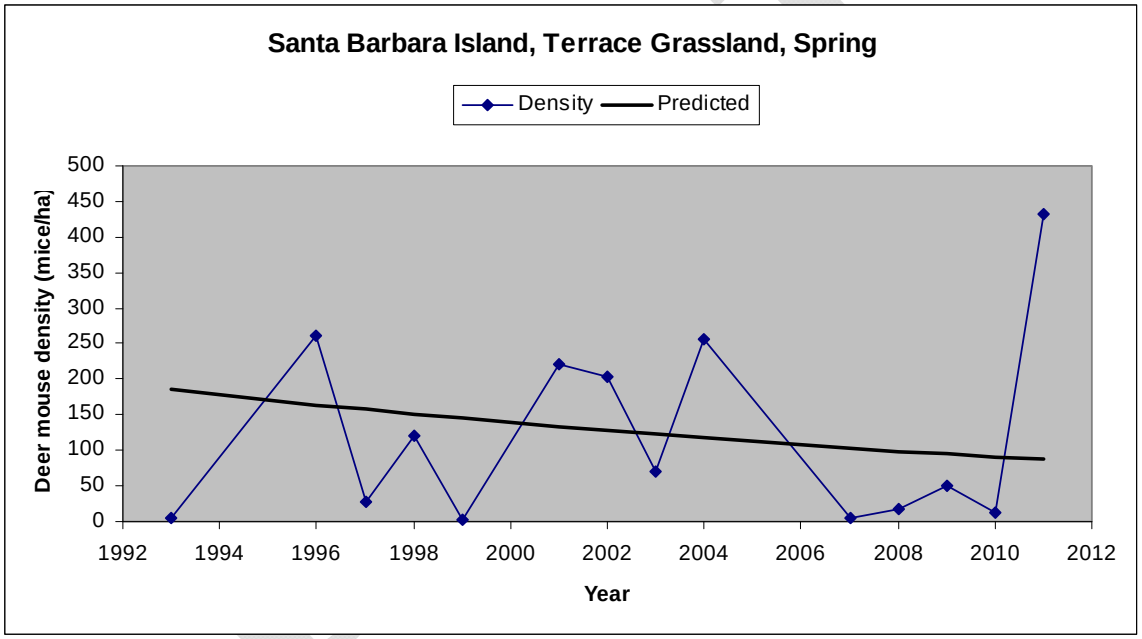
Figure 7. Annual deer mouse density estimates for Santa Barbara Island, Terrace Grassland Grid, during the fall.



For Santa Barbara Island, the Terrace Grassland Grid in the spring, the best model from those considered was a year only model. For these data (Figure 8) the trend was negative (the average annual rate of change was -4.1%) with the 95% confidence interval covering zero, hence the trend parameter was not statistically different from zero:

Parameter	DF	Estimate	Standard Error	Likelihood Ratio 95% Confidence Limits	
Intercept	1	89.2465	112.8544	-148.021	326.5144
year	1	-0.0422	0.0563	-0.1605	0.0762
Scale	1	7.9424	1.5010	5.7112	12.1165

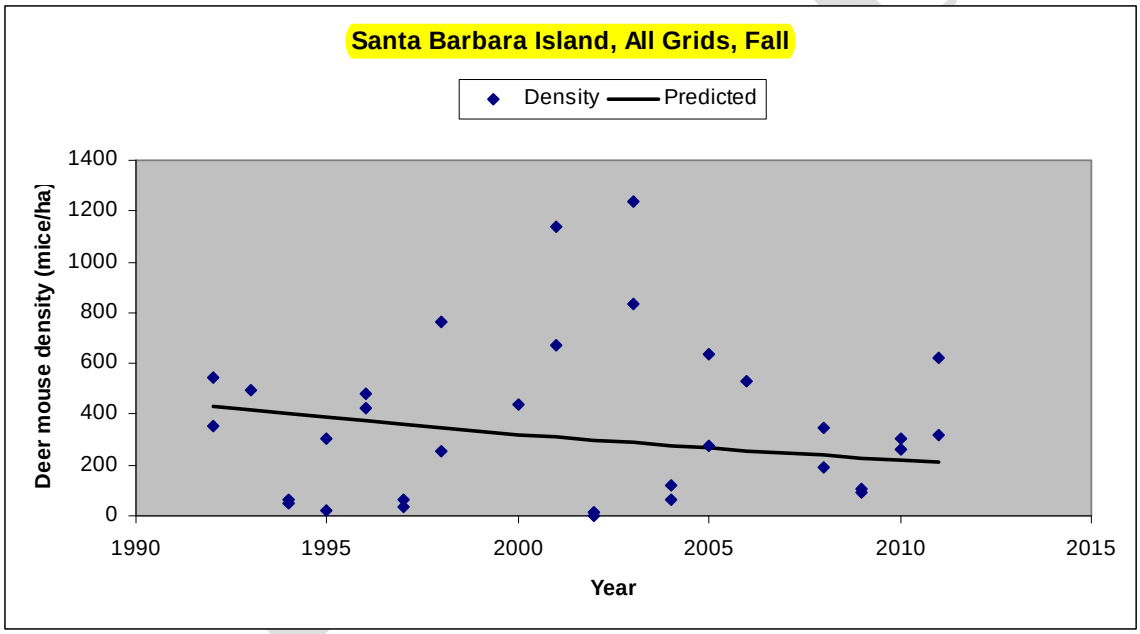
Figure 8. Annual deer mouse density estimates for Santa Barbara Island, Terrace Grassland Grid, during the spring.



For Santa Barbara Island, with grid data pooled during the fall, the best model from those considered was a year only model. For these data (Figure 9) the trend was negative (the average annual rate of change was -3.7%) with the 95% confidence interval barely covering zero at the upper bound, hence while suggestive of a trend the trend parameter was not statistically different from zero:

Parameter	DF	Estimate	Standard Error	Likelihood Ratio 95% Confidence Limits	
Intercept	1	81.2704	37.9776	4.5451	157.9957
year	1	-0.0377	0.0190	-0.0761	0.0006
Scale	1	5.6031	0.7004	4.4674	7.3160

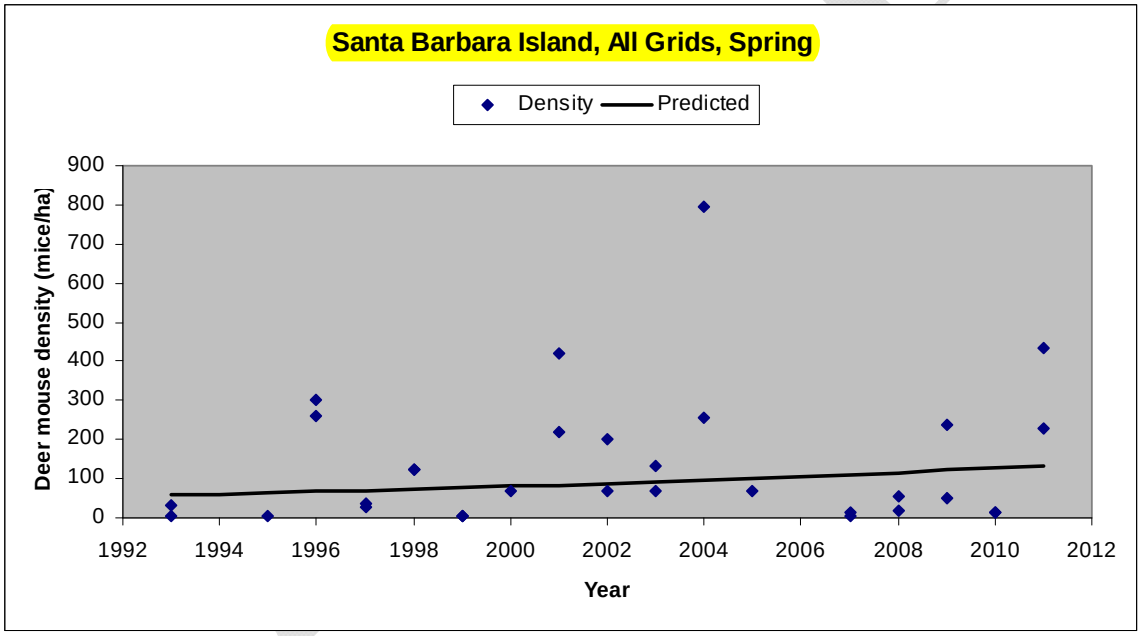
Figure 9. Annual deer mouse density estimates for Santa Barbara Island, all grids pooled, during the fall.



For Santa Barbara Island, with grid data pooled during the spring, the best model from those considered was a jday and year model. For these data (Figure 10) the trend was positive (the average annual rate of change was 4.6%) with the 95% confidence interval covering zero, hence the trend parameter was not statistically different from zero:

Parameter	DF	Estimate	Standard Error	Likelihood Ratio 95% Confidence Limits	
Intercept	1	-88.8342	65.5345	-221.503	43.8344
jday	1	0.0296	0.0125	0.0042	0.0550
year	1	0.0454	0.0326	-0.0207	0.1115
Scale	1	7.2579	0.9370	5.7472	9.5676

Figure 10. Annual deer mouse density estimates for Santa Barbara Island, all grids pooled, during the spring.

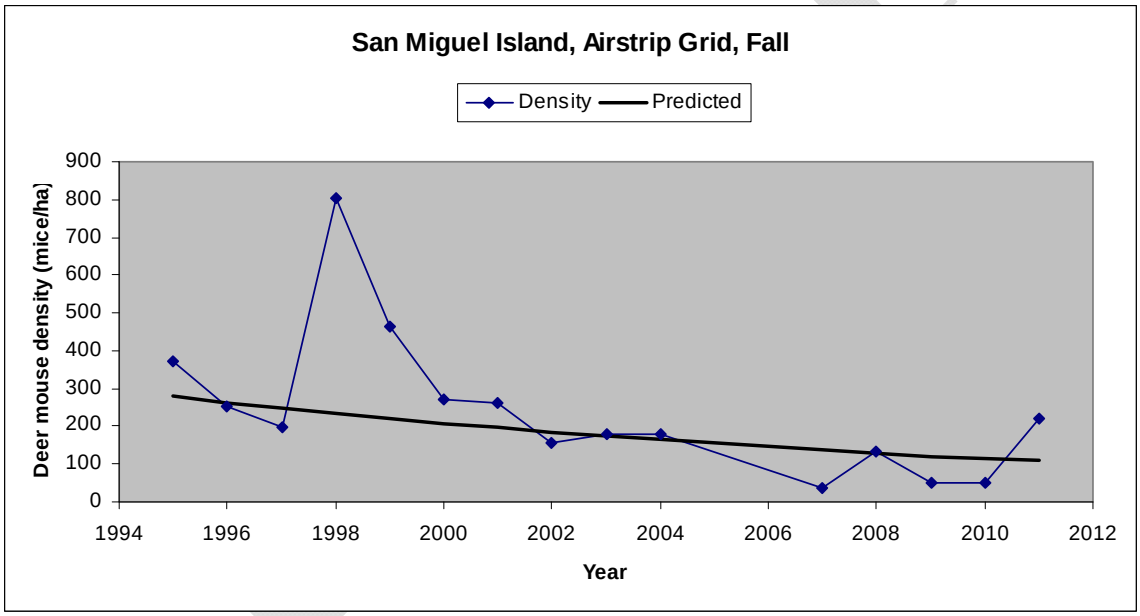


San Miguel Island:

For San Miguel Island, the Airstrip Grid in the fall, the best model from those considered was a year only model. For these data (Figure 11) the trend was negative (the average annual rate of change was -5.8%) with a 95% confidence interval that did not cover zero, hence the trend parameter is statistically different from zero:

Parameter	DF	Estimate	Standard Error	Likelihood Ratio 95% Confidence Limits	
Intercept	1	124.5167	48.8273	22.3501	226.6834
year	1	-0.0596	0.0244	-0.1107	-0.0085
Scale	1	3.8394	0.7010	2.7886	5.7629

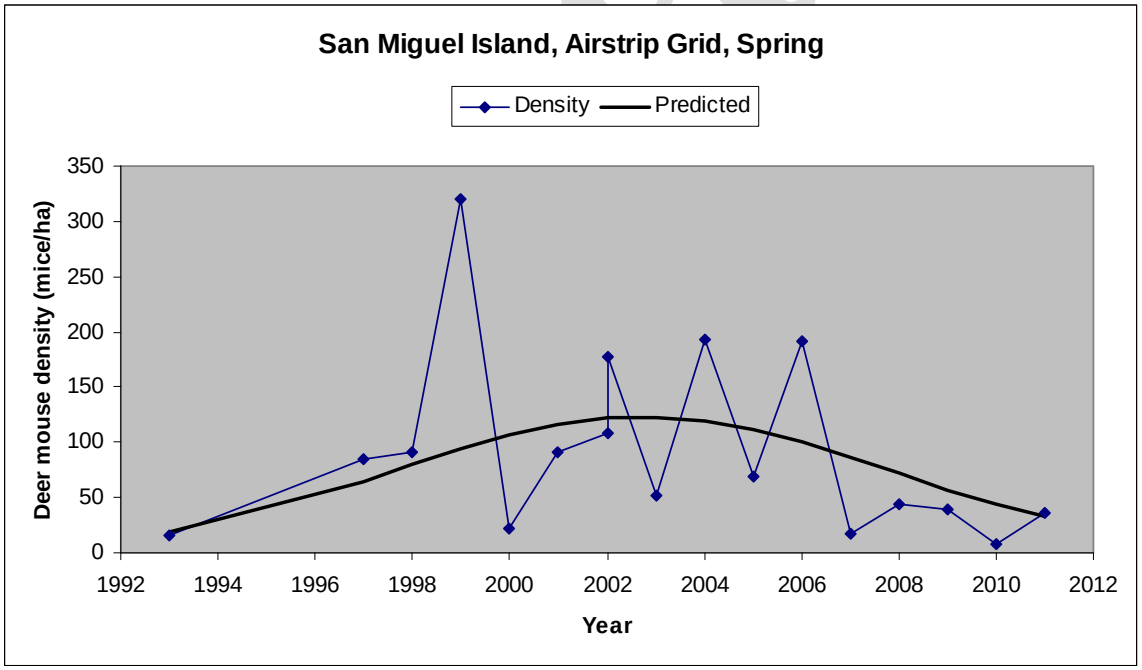
Figure 11. Annual deer mouse density estimates for San Miguel Island, Airstrip Grid, Fall.



For San Miguel Island, the Airstrip Grid in the spring, the best model from those considered included the variables year, and year^2. For these data (Figure 12) the predicted values suggest densities increased (the average annual rate of change was 20.3%) from 1993 to a peak in 2003, then declined (the average annual rate of change was -15.4%) from 2003 to 2011. For year and year^2 the 95% confidence intervals do not cover zero, indicating these parameters statistically differ from zero (before analysis years were rescaled from 1-19, with 1 = 1993 and 19 = 2011):

Parameter	DF	Estimate	Standard Error	Likelihood Ratio 95% Confidence Limits	
Intercept	1	2.5601	1.0291	0.4238	4.6965
year	1	0.4200	0.1858	0.0341	0.8058
year*year	1	-0.0196	0.0082	-0.0365	-0.0026
Scale	1	5.7089	0.9791	4.2194	8.3347

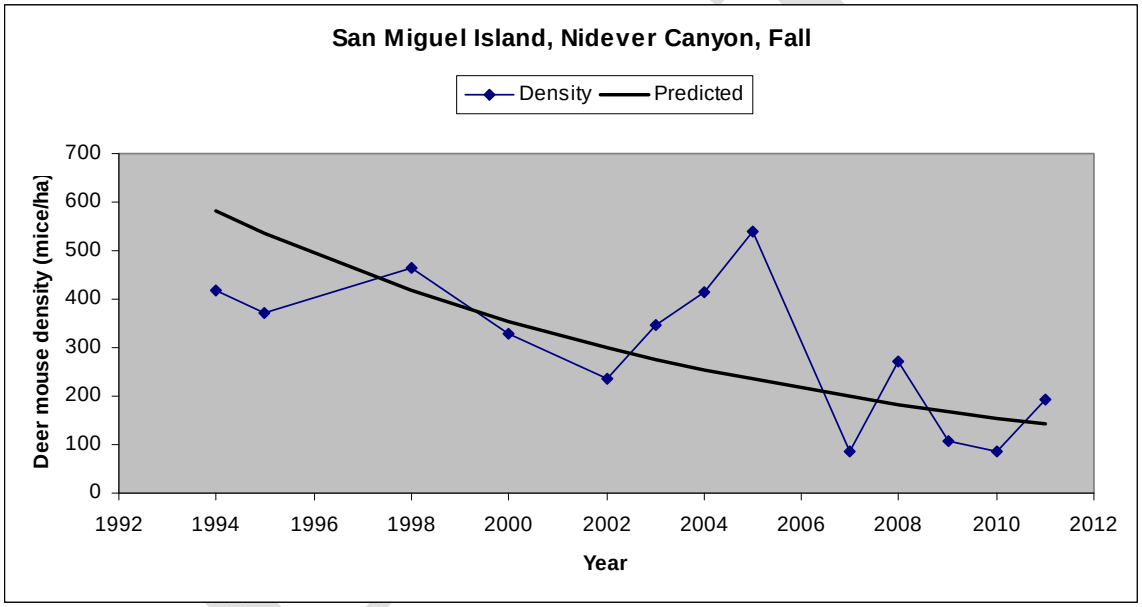
Figure 12. Annual deer mouse density estimates for San Miguel Island, Airstrip Grid, Spring.



For San Miguel Island, the Nidever Canyon Grid in the fall, the best model from those considered was a year only model. For these data (Figure 13) the trend was negative (the average annual rate of change was -8.0%) with a 95% confidence interval that did not cover zero, hence the trend parameter is statistically different from zero:

Parameter	DF	Estimate	Standard Error	Likelihood Ratio 95% Confidence Limits	
Intercept	1	171.8083	68.8407	26.2737	317.3428
year	1	-0.0830	0.0343	-0.1556	-0.0104
Scale	1	6.7008	1.3141	4.7655	10.4107

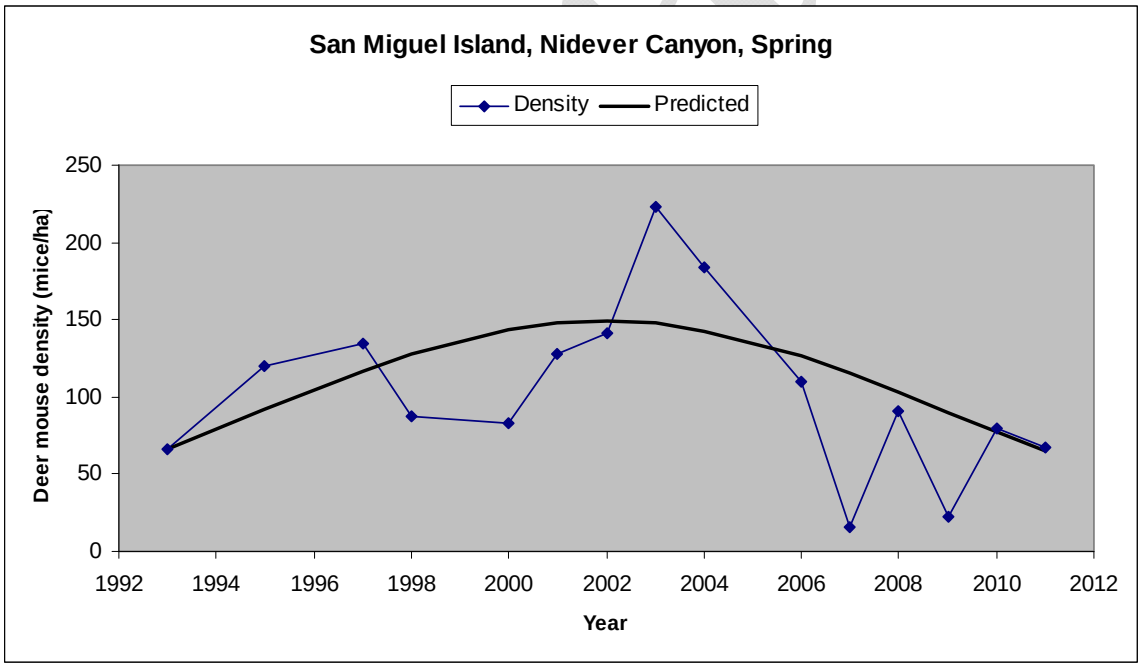
Figure 13. Annual deer mouse density estimates for San Miguel Island, Nidever Canyon Grid, Fall.



For San Miguel Island, the Nidever Canyon Grid in the spring, the best model from those considered included the variables year and year^2. For these data (Figure 14) the predicted values suggest densities increased (the average annual rate of change was 9.4%) from 1993 to a peak in 2002, then declined (the average annual rate of change was -8.8%) from 2002 to 2011. For year and year^2 the 95% confidence intervals do not cover zero, indicating these parameters statistically differ from zero (before analysis years were rescaled from 1-19, with 1 = 1993 and 19 = 2011):

Parameter	DF	Estimate	Standard Error	Likelihood Ratio 95% Confidence Limits	
Intercept	1	4.0047	0.1780	3.6305	4.3790
year	1	0.2013	0.0390	0.1194	0.2833
year*year	1	-0.0101	0.0020	-0.0143	-0.0060
Scale	1	2.6326	0.4975	1.8931	4.0162

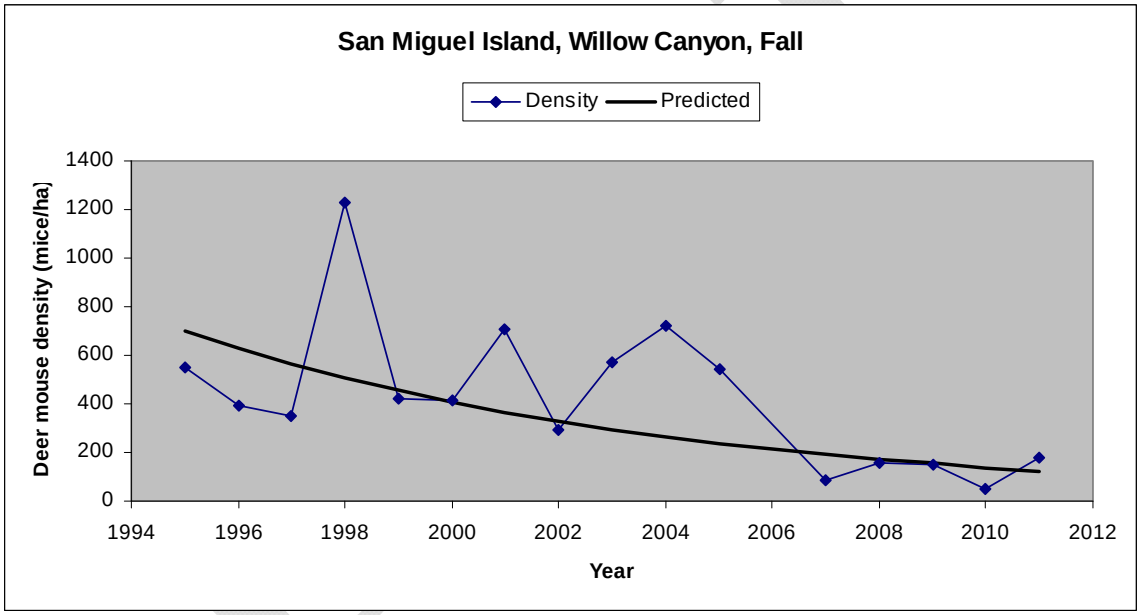
Figure 14. Annual deer mouse density estimates for San Miguel Island, Nidever Canyon Grid, Spring.



For San Miguel Island, the Willow Canyon Grid in the fall, the best model from those considered was a year only model. For these data (Figure 15) the trend was negative (the average annual rate of change was -10.2%) with a 95% confidence interval that did not cover zero, hence the trend parameter is statistically different from zero:

Parameter	DF	Estimate	Standard Error	Likelihood Ratio 95% Confidence Limits	
Intercept	1	221.4864	47.3912	122.7370	320.2358
year	1	-0.1077	0.0237	-0.1571	-0.0584
Scale	1	2.7296	0.4825	2.0006	4.0378

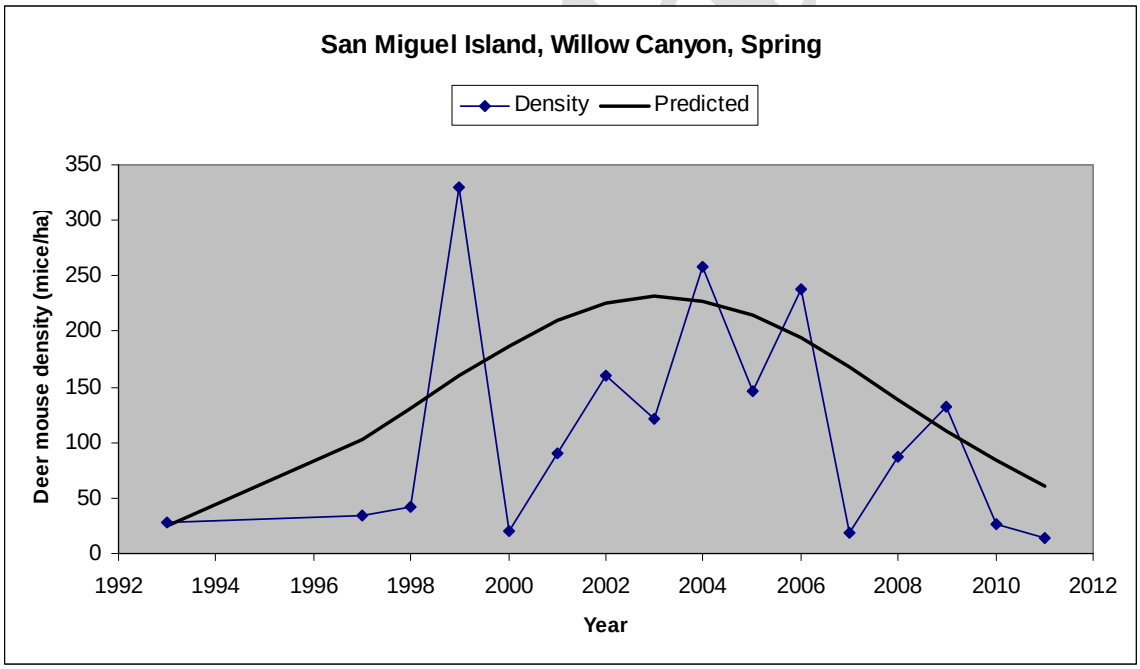
Figure 15. Annual deer mouse density estimates for San Miguel Island, Willow Canyon Grid, Fall.



For San Miguel Island, the Willow Canyon Grid in the spring, the best model from those considered included the variables year and year^2. For these data (Figure 16) the predicted values suggest densities increased (the average annual rate of change was 25.0%) from 1993 to a peak in 2003, then declined (the average annual rate of change was -15.4%) from 2003 to 2011. For year and year^2 the 95% confidence intervals do not cover zero, indicating these parameters statistically differ from zero (before analysis years were rescaled from 1-19, with 1 = 1993 and 19 = 2011):

Parameter	DF	Estimate	Standard Error	Likelihood Ratio 95% Confidence Limits	
Intercept	1	2.7536	0.6761	1.3448	4.1624
year	1	0.4829	0.1440	0.1829	0.7828
year*year	1	-0.0217	0.0075	-0.0372	-0.0061
Scale	1	4.1063	0.7259	3.0097	6.0744

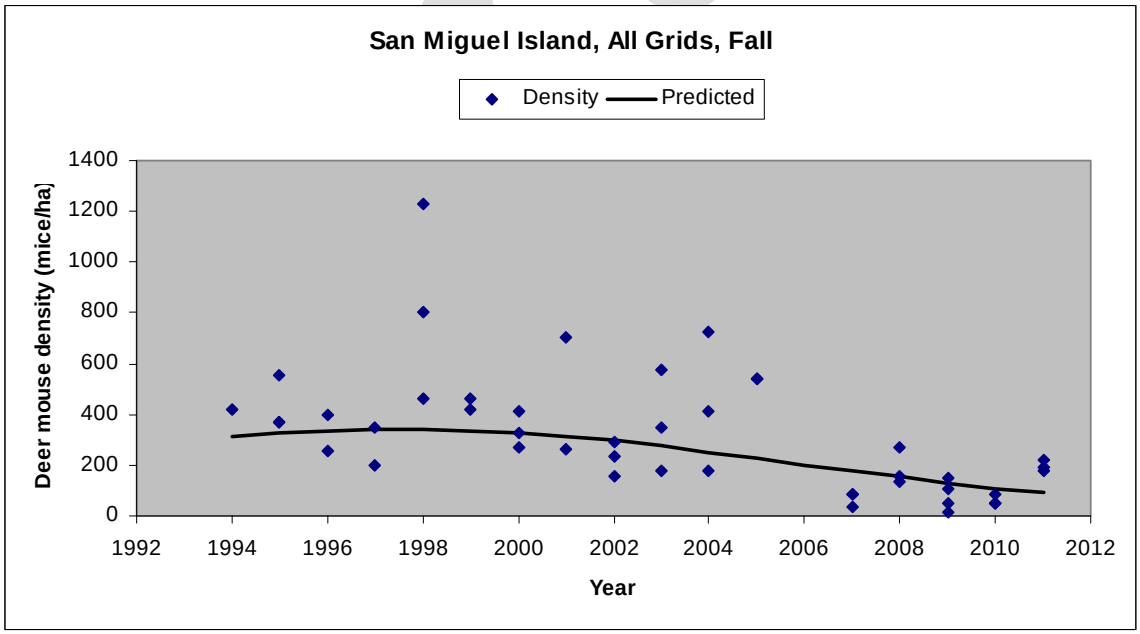
Figure 16. Annual deer mouse density estimates for San Miguel Island, Willow Canyon Grid, Spring.



For San Miguel Island, all grids pooled in the fall, the best model from those considered included the variables location_code, year, and year^2. For these data (Figure 17) the predicted values suggest densities increased (the average annual rate of change was 2.9%) from 1994 to a peak in 1997, then declined (the average annual rate of change was -9.1%) from 1997 to 2011. For the Airstrip Grid location code the 95% confidence interval does not cover zero, indicating density on this grid statistically differed from the Willow Canyon grid (this was the reference grid in this analysis). For year^2 the 95% confidence interval does not cover zero, indicating this parameter statistically differs from zero (before analysis years were rescaled from 1-18, with 1 = 1994 and 18 = 2011):

Parameter		DF	Estimate	Standard Error	Likelihood Ratio 95% Confidence Limits	
Intercept		1	5.9086	0.3481	5.2111	6.6061
Location_Code	AS	1	-0.5618	0.1856	-0.9336	-0.1900
Location_Code	NC	1	-0.0938	0.1726	-0.4396	0.2520
Location_Code	WC	0	0.0000	0.0000	0.0000	0.0000
year		1	0.0655	0.0695	-0.0738	0.2048
year*year		1	-0.0073	0.0034	-0.0142	-0.0005
Scale		1	4.4092	0.4700	3.6268	5.5193

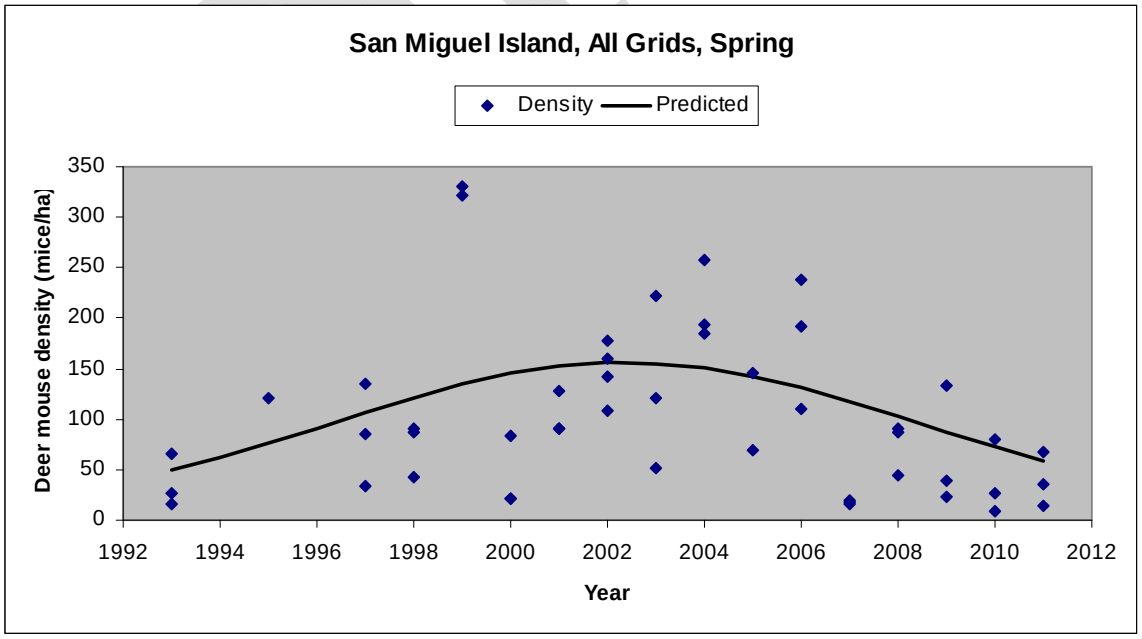
Figure 17. Annual deer mouse density estimates for San Miguel Island, All Grids, Fall.



For San Miguel Island, all grids pooled in the spring, the best model from those considered included the variables location_code, year, and year^2. For these data (Figure 18) the predicted values suggest densities increased (the average annual rate of change was 13.7%) from 1993 to a peak in 2002, then declined (the average annual rate of change was -10.3%) from 2002 to 2011. For the Airstrip Grid location code the 95% confidence interval does not cover zero, indicating density on this grid statistically differed from the Willow Canyon grid (this was the reference grid in this analysis). For year and year^2 the 95% confidence intervals do not cover zero, indicating these parameters statistically differ from zero (before analysis years were rescaled from 1-19, with 1 = 1993 and 19 = 2011):

Parameter		DF	Estimate	Standard Error	Likelihood Ratio 95% Confidence Limits	
Intercept		1	3.9455	0.3280	3.2892	4.6018
Location_Code	AS	1	-0.6315	0.2054	-1.0425	-0.2205
Location_Code	NC	1	-0.2773	0.1820	-0.6415	0.0869
Location_Code	WC	0	0.0000	0.0000	0.0000	0.0000
year		1	0.2737	0.0576	0.1584	0.3890
year*year		1	-0.0132	0.0028	-0.0189	-0.0075
Scale		1	4.6681	0.4815	3.8626	5.7979

Figure 18. Annual deer mouse density estimates for San Miguel Island, All Grids, Spring.



Discussion

In the discussion below I summarize the major patterns I found in the trend data for each island. However, because the grids were not placed according to any probabilistic sampling design, it is important to realize that valid statistical inferences from the grids (on an island) to the entire island can not be made. However, inferences to the individual grids and the grids in aggregate can be made and are valid. In all cases below the patterns described pertain to the grids only, not the entire island. I close the discussion with some comments on data issues.

Anacapa Island

The data for Anacapa Island are old and incomplete relative to the other islands and very few inferences can be drawn. Clearly it is safe to conclude that fall densities of mice far exceeded spring densities of mice, and there seems to be some evidence for a long-term increase in fall and spring deer mouse densities on the East Islet Grid. In contrast, on the Middle and West Islet Grids there is no real evidence for a trend and even if there was, the fact that the data were last collected in 1998 means any patterns that might have existed are no longer relevant. If more recent data were collected on the Middle and West Islet Grids, it would be possible to assess whether there might be density trends that mirror those on the East Islet Grid.

Santa Barbara Island

The data for Santa Barbara Island generally do not provide strong evidence for trends in density, either within grids or across grids, and the estimated trends are contradictory. For the Terrace Coreopsis Grid the fall data shows a slight decline in density, whereas the spring data for that same grid show a slight increase for the same period. In contrast, the Terrace Grassland Grid shows the complete opposite: the fall data show a strong increase in density up until 2005, whereas the spring data show a slight decline over the same period. In short, within a season the two grids show opposite patterns, and within each grid the two seasons show opposite patterns.

The slope parameters for the Terrace Grassland Grid fall data statistically differ from zero, so at least in this case the evidence for a trend (increase followed by a decrease in densities) is strong. When the data are pooled across grids, the fall data show a slight decline in density whereas the spring data show a slight increase in density over the same period of time, though in both cases the estimated slope parameter does not statistically differ from zero.

Over the periods sampled, average fall densities were more than twice spring densities on both grids.

San Miguel Island

The data for San Miguel Island provide strong evidence for trends in density over the period sampled, however the patterns of those trends differed between seasons. For the fall data, all three grids showed a strong negative trend in densities (in all cases the slope parameters statistically differed from zero), and when the data were pooled across all grids the quadratic parameter (but not the linear parameter) was negative and statistically differed from zero, providing strong evidence for a decline in densities

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beginning in 1997. In contrast, for the spring data all three grids showed an initial increase in densities followed by a decline in densities (in all cases the parameters on the linear and quadratic terms statistically differed from zero). When the data were pooled across all grids, the model indicated there was an increase in densities up until 2002, which was then followed by a decline in densities through 2011 (the parameters on the linear and quadratic terms statistically differed from zero). Taken collectively, the fall and spring data provide strong evidence for a decline in deer mouse densities between 2002 and 2011.

Data for both the fall and spring indicate that average mouse densities on the Airstrip Grid were higher than on the Willow Canyon Grid, but did not differ from the Nidever Canyon Grid. Average mouse densities on the Nidever Canyon Grid did not differ from the Willow Canyon Grid.

Data Issues and Considerations

Generally speaking the mouse monitoring data on all three islands are of very high quality. Within each grid the sampling protocol was rigorous, mostly consistent through time, and the fact that consideration was given to the estimation of detection probabilities is commendable. As is typical with most long-term data sets, where staff and equipment change through time, certain data quality issues always seem to arise. In preparing to analyze these data I encountered multiple issues that required a great deal of time and effort to reconcile and correct. I have documented these issues in a series of emails to National Park Service (NPS) staff (Lena Lee) and will not repeat them here. However, I hope that as part of the monitoring program review we can revisit some of those issues to see if improvements in data collection or stewardship can be made.

The models I used for estimating abundance (i.e., Huggins 1991) are very flexible and robust and seemed to perform well for the deer mice data, except under two general conditions. The first was when there were few (or no) recaptures, and the second was when the number of new captures increased with each successive night of trapping. In both cases abundance estimates under most models were wildly inflated and standard errors were unrealistically large (or zero). One solution that I'd urge to NPS to consider is to build flexibility into their field schedules to allow an increase in the number of trapping occasions on a grid when daily summaries of the data indicate recaptures are low or the number of new captures has increased each day. Under these circumstances, I suspect adding one or two nights of trapping would yield much better data for estimating abundance.

I mentioned in the methods that I did not use autoregressive terms in the trend models due to missing years of data (within a particular season). Missing data also precludes analysis of oscillatory patterns in the data, which was beyond the scope of my analysis but nevertheless was suggested by some of the data (e.g., Figures 5, 8, and 12). If there is a desire by the NPS to, at some point in the future, exploit models with autoregressive terms or investigate oscillatory patterns, then a firm commitment to obtaining annual data is imperative. Along those same lines, there were 11 "Summer" data sets and 4 "Winter" data sets. In some cases it appeared these were intended to "make up" for missing a spring or fall season of trapping. Because of the huge variation in seasonal abundances I observed in the data I was not able to use any of the Summer or Winter data in the trend analyses (it would introduce bias or inflate error). Consequently,

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I'd recommend not trapping during these seasons unless there are other compelling reasons to do so. However, "making up" for a missed fall or spring trapping season should not be considered a compelling enough reason, as the data simply aren't useful for the trend analyses.

I restricted my analysis in this report to estimating deer mouse density and temporal trends in abundance. At some point some thought should be put into what additional analyses using the existing data would be of value to the NPS. For example, are there questions that could be addressed using the sex, weight, age, or breeding status data? I did not explore any such analyses because: 1) I didn't have time, and 2) I got no indication such analyses were desired or would be useful. Nevertheless, if other data in this long term data set can be mined to yield useful information, then it would be desirable to do so.

Data on temporal trends in density have limited value outside the realm of monitoring the resource of interest. However, these data are expensive to collect and have huge potential to address many important questions. First and foremost, if patterns in abundance are observed then a natural question is "what is driving those trends?" Unfortunately, without a corresponding time series of ancillary (covariate) data, or experimental manipulation of the system (e.g., Before-After Control-Impact, or BACI design), it's usually not possible to ascertain what is driving trends. Furthermore, without ancillary data it's not possible to address other questions about the system in which the resource (in this case deer mice) is embedded. I recommend that serious and deep thought be given to why these deer mouse abundance data are being collected, why they should continue to be collected, and how they can be made even more valuable for understanding and managing the island system of which they are a part. In the end it all comes down to goal and objectives, and those should be clearly articulated.

Finally, in executing the analyses above I encountered a couple of minor database issues the NPS should consider fixing. All of these fall into the category of "storing two distinct pieces of information in a single field" (i.e., a single variable). The first occurrence is in the "qry_DeerMiceCaptureData.xls" file. The "Trap_Number" variable contains both the *x* and *y* coordinates of the trap, which I had to extract so I could compute MMDM for individual mice. I would recommend splitting this variable into two variables, one for each coordinate, so it will be easier to use the information on trap location. The second occurrence is in the "qry_CountOfTrapNightsAndCaptures_20120308.xls" file. The "Grid_Size" variable encodes the number of traps along both the *x* and *y* axes of the trapping grid. Because the format used is inconsistent (e.g., 10x10 versus 10X10, 5x10 versus 05x10) it is difficult to extract the number of traps along the *x* and *y* axes in a simple, automated way. I ended up hard-coding the translation of the Grid_Size to get at the number of traps along the *x* and *y* axes, which was no big deal since the number of variations was small. However, if the number of variants becomes large it would become much more difficult to extract the needed information. The last occurrence pertains to the "Ind" variable in the "xtab_SiteNightAndInd_DeerMice2_20120308.xls" file and the "Tag_Number" and "Individual_Number" variables in the "qry_DeerMiceCaptureData.xls" file. In first file "Ind" contains a value with a prefix and suffix (separated by a dot) to identify a mouse, in the second file a mouse is uniquely identified by "Tag_Number" containing only the prefix and "Individual_Number" containing only the suffix. I recommend that in every

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file containing mouse identifiers the latter format be used (prefix and suffix in different fields) and that variable names remain consistent across files (or data tables as the case may be).

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Appendix A. Deer mouse (*Peromyscus maniculatus* subsp.) density estimates by island, grid, and trapping date.

Table A1.1. Density estimates for Anacapa Island, East Islet Grid. Trap Date is the date trapping of the grid began; Year is the year of trapping; Mt+1 is the number of distinct deer mice trapped and retained in the data set for analysis; Nhat is estimated deer mouse abundance on the trapping grid; Se(Nhat) is the standard error of the deer mouse abundance estimate; LCI(Nhat) and UCI(Nhat) are the lower and upper bounds of the 95% CI of the deer mouse abundance estimate; A(W) is the estimated area (hectares) sampled by the trapping grid; Se[A(W)] is the standard error of the estimated trapping area of the grid; Dhat is the estimated density of deer mice (mice/hectare) on the trapping grid; Se(Dhat) is the standard error of the estimated density of deer mice on the trapping grid; LCI(Dhat) and UCI(Dhat) are the lower and upper bounds of the 95% CI of the deer mouse density estimate on the trapping grid.

Anacapa Island, East Islet Grid

Trap Date	Year	Mt+1	Nhat	Se(Nhat)	LCI(Nhat)	UCI(Nhat)	A(W)	Se[A(W)]	Dhat	Se(Dhat)	LCI(Dhat)	UCI(Dhat)
5-Nov-97	1997	24	28.8	7.92	25.1	45.1	0.663	0.0699	43.4	12.73	36.9	110.3
18-Mar-98	1998	10	10.3	0.72	10.1	11.8	0.937	0.1025	11	1.42	10.7	20.4
18-Mar-10	2010	15	15.2	0.57	15	16.4	0.893	0.1052	17	2.1	16.8	31.1
21-Oct-10	2010	62	132	31.23	102.7	183.6	0.521	0.028	253.8	61.34	176.6	434.4
1-Apr-11	2011	19	22.7	8.11	19.7	39.5	0.771	0.0716	29.4	10.83	25	91.7
24-Oct-11	2011	108	144	26.19	123.4	191.4	0.569	0.0226	252.8	47.07	206.9	422.2

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Table A1.2. Density estimates for Anacapa Island, Middle Islet Grid. Trap Date is the date trapping of the grid began; Year is the year of trapping; Mt+1 is the number of distinct deer mice trapped and retained in the data set for analysis; Nhat is estimated deer mouse abundance on the trapping grid; Se(Nhat) is the standard error of the deer mouse abundance estimate; LCI(Nhat) and UCI(Nhat) are the lower and upper bounds of the 95% CI of the deer mouse abundance estimate; A(W) is the estimated area (hectares) sampled by the trapping grid; Se[A(W)] is the standard error of the estimated trapping area of the grid; Dhat is the estimated density of deer mice (mice/hectare) on the trapping grid; Se(Dhat) is the standard error of the estimated density of deer mice on the trapping grid; LCI(Dhat) and UCI(Dhat) are the lower and upper bounds of the 95% CI of the deer mouse density estimate on the trapping grid.

Anacapa Island, Middle Islet Grid

Trap Date	Year	Mt+1	Nhat	Se(Nhat)	LCI(Nhat)	UCI(Nhat)	A(W)	Se[A(W)]	Dhat	Se(Dhat)	LCI(Dhat)	UCI(Dhat)
18-Oct-94	1994	59	83.8	13.11	72.1	106.1	0.569	0.039	147.3	25.13	119	228.3
1-Apr-95	1995	17	19.7	3.11	17.8	25.8	1.608	0.3621	12.2	3.34	10.7	30.6
1-Nov-95	1995	75	148	34.46	116	205.4	0.743	0.1129	199.4	54.97	136.4	374.2
4-Oct-96	1996	110	126	7.76	118.6	138.7	0.58	0.0221	216.7	15.7	199	267.4
25-Mar-97	1997	11	15.2	4.61	12.3	24.2	0.892	0.2189	17	6.51	12.9	48.1
22-Oct-97	1997	47	56.2	6.95	50.9	68.9	0.331	0.0241	170	24.34	148.5	264.1
15-Apr-98	1998	16	23.4	6.77	18.7	36.3	0.849	0.1077	27.5	8.64	20.6	63

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Table A1.3. Density estimates for Anacapa Island, West Islet Grid. Trap Date is the date trapping of the grid began; Year is the year of trapping; Mt+1 is the number of distinct deer mice trapped and retained in the data set for analysis; Nhat is estimated deer mouse abundance on the trapping grid; Se(Nhat) is the standard error of the deer mouse abundance estimate; LCI(Nhat) and UCI(Nhat) are the lower and upper bounds of the 95% CI of the deer mouse abundance estimate; A(W) is the estimated area (hectares) sampled by the trapping grid; Se[A(W)] is the standard error of the estimated trapping area of the grid; Dhat is the estimated density of deer mice (mice/hectare) on the trapping grid; Se(Dhat) is the standard error of the estimated density of deer mice on the trapping grid; LCI(Dhat) and UCI(Dhat) are the lower and upper bounds of the 95% CI of the deer mouse density estimate on the trapping grid.

Anacapa Island, West Islet Grid

Trap Date	Year	Mt+1	Nhat	Se(Nhat)	LCI(Nhat)	UCI(Nhat)	A(W)	Se[A(W)]	Dhat	Se(Dhat)	LCI(Dhat)	UCI(Dhat)
20-Mar-93	1993	6	12.9	10.86	7.6	35.2	0.397	0	32.5	27.35	17.1	170.1
29-Mar-95	1995	4	4.2	0.67	4	5.6	0.397	0	10.7	1.7	10.1	21.1
1-Nov-95	1995	91	123	14.17	109.5	146.2	0.541	0.0205	227	27.52	192.8	308.8
19-Oct-96	1996	24	25.9	2.56	24.5	31.1	0.405	0.0398	63.9	8.87	59.6	111.8

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Table A2.1. Density estimates for Santa Barbara Island, Terrace Coreopsis Grid. Trap Date is the date trapping of the grid began; Year is the year of trapping; Mt+1 is the number of distinct deer mice trapped and retained in the data set for analysis; Nhat is estimated deer mouse abundance on the trapping grid; Se(Nhat) is the standard error of the deer mouse abundance estimate; LCI(Nhat) and UCI(Nhat) are the lower and upper bounds of the 95% CI of the deer mouse abundance estimate; A(W) is the estimated area (hectares) sampled by the trapping grid; Se[A(W)] is the standard error of the estimated trapping area of the grid; Dhat is the estimated density of deer mice (mice/hectare) on the trapping grid; Se(Dhat) is the standard error of the estimated density of deer mice on the trapping grid; LCI(Dhat) and UCI(Dhat) are the lower and upper bounds of the 95% CI of the deer mouse density estimate on the trapping grid.

Santa Barbara Island, Terrace Coreopsis Grid

Trap Date	Year	Mt+1	Nhat	Se(Nhat)	LCI(Nhat)	UCI(Nhat)	A(W)	Se[A(W)]	Dhat	Se(Dhat)	LCI(Dhat)	UCI(Dhat)
22-Sep-92	1992	232	295	21.8	273.1	329.6	0.54	0.0128	546.5	42.34	488.3	662.1
3-Mar-93	1993	22	22.9	1.35	22.2	25.6	0.672	0.042	34.1	2.92	32.8	50.8
13-Oct-93	1993	208	267	24.16	243.3	305.9	0.541	0.0197	493.1	48.11	431.9	633.5
28-Sep-94	1994	48	53.8	5.36	50.1	64	0.891	0.1303	60.4	10.65	54.6	114.8
1-Mar-95	1995	3	3	0.07	3	3.1	0.521	0.0656	5.8	0.74	5.8	8.7
7-Nov-95	1995	31	148	93.61	78	321	0.489	0.0959	302.1	196.85	121.6	1042.9
27-Mar-96	1996	131	167	16.86	151.1	194.8	0.556	0.0188	299.9	31.94	261.2	397
16-Oct-96	1996	127	253	39.79	211.8	314.9	0.529	0.0273	478.6	79.05	366.7	689.1
19-Mar-97	1997	19	22.6	3.8	20.2	30	0.613	0.1241	36.9	9.62	31.6	86.2
29-Oct-97	1997	25	39.6	9.34	31.8	56.1	0.608	0.0527	65.1	16.31	48.3	121.4
9-Apr-98	1998	50	80.7	13.38	67.9	102.6	0.66	0.0776	122.3	24.74	93.2	199.5
11-Nov-98	1998	162	414	152.4	284.6	680.4	0.541	0.0469	766.1	288.66	452.5	1723.7
5-Mar-99	1999	1	1				0.397	0	2.5			
21-Apr-00	2000	43	47.5	6.3	44.2	60.3	0.68	0.0343	69.9	9.9	64	118.5
5-Aug-00	2000	190	266	24.22	240.9	303.6	0.707	0.0502	376.1	43.34	318.9	498.7
28-Oct-00	2000	190	242	48.92	208.8	335.6	0.55	0.0314	440.2	92.21	364.4	814.4
14-Mar-01	2001	143	204	41.15	170.7	277.6	0.488	0.0199	418.3	86	330.1	716.6
19-Sep-01	2001	168	314	94.1	236	480.4	0.275	0.0157	1141	347.77	774.9	2323.5
16-Apr-02	2002	44	49.4	5.64	45.8	60.4	0.714	0.05	69.2	9.26	62.8	111
19-Jul-02	2002	7	8	1.41	7.3	10.9	0.991	0.0945	8.1	1.62	7.2	16.3
21-Sep-02	2002	2	2.6	1.38	2.1	5.5	0.176	0	14.8	7.8	11.6	59.4

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3-Apr-03	2003	61	86.7	21.77	70.9	127.4	0.658	0.0492	131.8	34.46	101.6	265.5
5-Oct-03	2003	144	317	50.16	263.7	393.5	0.256	0.015	1239	208.9	937.2	1785.1
4-Apr-04	2004	172	394	145.06	274.8	651.6	0.495	0.016	796.6	294.24	486.8	1796.6
7-Nov-04	2004	27	37.2	10.1	30.5	56.7	0.304	0.0336	122.3	35.63	94.8	273
19-Mar-05	2005	40	51.6	11.3	44	73.3	0.752	0.0733	68.6	16.38	56	137.9
30-Oct-05	2005	269	350	36.57	315.6	410.5	0.549	0.0215	637.4	71.03	550.1	850.7
17-Sep-06	2006	198	284	29.98	253.3	330.9	0.537	0.0268	528.2	61.64	445.5	700
25-Mar-07	2007	6	9.7	4.46	7.1	18.6	0.696	0.1113	13.9	6.7	9.4	44.6
6-Dec-07	2007	40	44.3	5.24	41.3	54.8	0.872	0.0537	50.8	6.76	46.5	82.8
23-Mar-08	2008	38	41.2	3.99	38.9	49.2	0.755	0.0886	54.6	8.28	50.7	99.7
23-Nov-08	2008	142	171	11.32	160.1	189.4	0.498	0.0263	343.8	29.05	308.6	432
12-Mar-09	2009	65	120	54.03	84.2	224.2	0.505	0.0186	238.2	107.28	150.7	675.3
25-Oct-09	2009	67	68.8	2.02	67.6	72.8	0.659	0.0241	104.4	4.89	101.9	130.1
1-Mar-10	2010	8	9	1.7	8.2	12.5	0.75	0.1915	11.9	3.75	10.7	35.1
21-Oct-10	2010	115	186	24.63	160.5	224.3	0.614	0.0569	302.1	48.77	238.9	442.4
4-Mar-11	2011	112	131	14.84	119.4	157.9	0.566	0.0197	230.6	27.42	205.7	334.6
1-Sep-11	2011	278	375	36.01	338.9	432.2	0.532	0.0179	705.2	71.74	609.6	906.4
13-Oct-11	2011	183	320	31.05	285.2	365.5	0.516	0.0171	619.4	63.58	521.1	775.7

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Table A2.2. Density estimates for Santa Barbara Island, Terrace Grassland Grid. Trap Date is the date trapping of the grid began; Year is the year of trapping; Mt+1 is the number of distinct deer mice trapped and retained in the data set for analysis; Nhat is estimated deer mouse abundance on the trapping grid; Se(Nhat) is the standard error of the deer mouse abundance estimate; LCI(Nhat) and UCI(Nhat) are the lower and upper bounds of the 95% CI of the deer mouse abundance estimate; A(W) is the estimated area (hectares) sampled by the trapping grid; Se[A(W)] is the standard error of the estimated trapping area of the grid; Dhat is the estimated density of deer mice (mice/hectare) on the trapping grid; Se(Dhat) is the standard error of the estimated density of deer mice on the trapping grid; LCI(Dhat) and UCI(Dhat) are the lower and upper bounds of the 95% CI of the deer mouse density estimate on the trapping grid.

Santa Barbara Island, Terrace Grassland Grid

Trap Date	Year	Mt+1	Nhat	Se(Nhat)	LCI(Nhat)	UCI(Nhat)	A(W)	Se[A(W)]	Dhat	Se(Dhat)	LCI(Dhat)	UCI(Dhat)
22-Sep-92	1992	222	270	20.76	250.4	304.2	0.771	0.0322	350.7	30.63	313.4	443.3
3-Mar-93	1993	6	7.9	2.57	6.5	13.1	1.297	0.2426	6.1	2.25	4.8	17.3
17-Jul-93	1993	149	268	63.59	211	376.1	0.53	0.0232	505	121.89	363.6	888.9
28-Jun-94	1994	41	62.6	23.76	47.8	109.2	0.457	0.0394	136.8	53.08	97.7	367.3
8-Nov-94	1994	19	30.4	11.04	23	51.6	0.659	0.0522	46.1	17.1	32.3	116.1
7-Nov-95	1995	12	24.7	13.47	16.2	51	1.076	0.8213	23	19.33	12.4	121.7
27-Mar-96	1996	101	142	15.95	126.1	167.5	0.543	0.0227	261.1	31.29	220.2	350.5
16-Oct-96	1996	85	215	143.44	126	496.6	0.504	0.0319	426.4	285.3	213.3	1656.2
19-Mar-97	1997	14	19	11.53	14.9	42.9	0.712	0.105	26.7	16.49	20.1	122.4
29-Oct-97	1997	12	16.2	6.76	13	30.1	0.489	0.0554	33.1	14.24	25.4	106.5
9-Apr-98	1998	49	58	4.97	53.6	66.5	0.476	0.0362	121.8	13.92	108.1	171.6
11-Nov-98	1998	47	113	44.48	76.6	192.2	0.449	0.0342	251	100.71	147.9	600.7
27-Mar-99	1999	2	2	0.1	2	2.2	0.696	0.3339	2.9	1.39	2.9	8.3
13-Apr-01	2001	91	114	9.08	105.3	128.8	0.52	0.027	220	20.87	194	282
19-Sep-01	2001	93	175	26.8	147	216.4	0.26	0.0324	671.3	132.1	499.7	1050.1
16-Apr-02	2002	44	132	54.27	86.2	227.2	0.65	0.1441	202.9	92.99	107.6	525.6
19-Jul-02	2002	0	0				0.397		0			
21-Sep-02	2002	0	0				0.176		0			
2-Apr-03	2003	51	64.7	10.91	56.5	84.9	0.93	0.0975	69.5	13.76	58	124.4
5-Oct-03	2003	123	223	26.82	194	263.4	0.266	0.0195	837.4	117.75	667.9	1146.3
1-Apr-04	2004	101	145	13.44	130.7	165.5	0.563	0.0299	257.3	27.49	219.2	331.9

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7-Nov-04	2004	5	11.2	8.63	6.6	28.7	0.176	.	63.6	48.9	33	296.9
27-Oct-05	2005	124	160	15.72	144.7	185.5	0.576	0.024	277.3	29.62	240.8	366.1
22-Mar-07	2007	3	3.5	1.05	3.1	5.7	0.589	0	6	1.78	5.2	15.9
10-Dec-07	2007	9	9	0.16	9	9.3	0.896	0.2439	10.1	2.75	10	20.4
20-Mar-08	2008	16	16.7	1.21	16.2	19.2	1.021	0.2297	16.4	3.86	15.7	42.3
20-Nov-08	2008	70	102	36.31	79.6	173.3	0.524	0.0227	193.9	69.79	143.5	501.2
15-Mar-09	2009	34	35.4	1.55	34.5	38.5	0.688	0.0437	51.5	3.97	49.6	73
22-Oct-09	2009	36	60	25.9	43.7	110.7	0.666	0.0379	90.1	39.16	60.4	257.5
5-Mar-10	2010	12	12.8	1.29	12.2	15.5	1.088	0.1469	11.8	1.98	11.1	23.6
25-Oct-10	2010	63	134	34.57	102	191.7	0.519	0.0682	258.1	74.3	171.9	492
7-Mar-11	2011	169	212	18.83	194.4	243.2	0.491	0.0237	432.9	43.67	379.9	565.4
16-Oct-11	2011	95	155	18.58	135.9	184	0.492	0.0227	315.7	40.45	258.4	423.3

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Table A3.1. Density estimates for San Miguel Island, Airstrip Grid. Trap Date is the date trapping of the grid began; Year is the year of trapping; Mt+1 is the number of distinct deer mice trapped and retained in the data set for analysis; Nhat is estimated deer mouse abundance on the trapping grid; Se(Nhat) is the standard error of the deer mouse abundance estimate; LCI(Nhat) and UCI(Nhat) are the lower and upper bounds of the 95% CI of the deer mouse abundance estimate; A(W) is the estimated area (hectares) sampled by the trapping grid; Se[A(W)] is the standard error of the estimated trapping area of the grid; Dhat is the estimated density of deer mice (mice/hectare) on the trapping grid; Se(Dhat) is the standard error of the estimated density of deer mice on the trapping grid; LCI(Dhat) and UCI(Dhat) are the lower and upper bounds of the 95% CI of the deer mouse density estimate on the trapping grid.

San Miguel Island, Airstrip Grid

Trap Date	Year	Mt+1	Nhat	Se(Nhat)	LCI(Nhat)	UCI(Nhat)	A(W)	Se[A(W)]	Dhat	Se(Dhat)	LCI(Dhat)	UCI(Dhat)
7-Apr-93	1993	26	28.7	2.56	26.9	33.6	1.876	0.2969	15.3	2.77	14	30.4
8-Feb-95	1995	35	38.2	2.71	36.2	43.2	0.598	0.0401	63.8	6.22	59.4	91.4
11-Oct-95	1995	143	220	44.61	181.3	297.1	0.594	0.0383	370.3	78.7	284	629.5
24-Oct-96	1996	126	155	16.08	140.6	182.3	0.609	0.0242	253.9	28.24	222.7	346.4
24-Mar-97	1997	40	57.9	10.7	48.8	76.6	0.68	0.0664	85.2	17.75	66.8	146.2
10-Jul-97	1997	147	160	6.52	153.8	170.7	0.615	0.0336	259.6	17.7	243.8	327.4
11-Oct-97	1997	112	114	2.85	112.4	119.7	0.582	0.0188	195.6	7.99	192.7	243.2
20-Mar-98	1998	47	55.3	10.87	49.3	77.2	0.612	0.0299	90.4	18.28	78.7	176.4
14-Oct-98	1998	242	408	63.21	344.8	508.6	0.508	0.0206	803	128.64	631.6	1164.1
24-May-99	1999	157	195	18.36	178.4	226	0.609	0.0256	320.9	33.01	281.9	423.3
31-Oct-99	1999	172	279	52.98	230.5	368	0.602	0.0215	463.3	89.45	355.6	736.6
31-Mar-00	2000	19	19.6	0.98	19.1	21.6	0.886	0.1028	22.1	2.79	21.5	40.5
4-Oct-00	2000	150	168	8.54	160.3	182.5	0.625	0.0242	269.1	17.18	249.9	324.9
18-Apr-01	2001	59	63.6	3.36	61	69.7	0.704	0.0442	90.3	7.4	84.9	122.5
3-Nov-01	2001	138	158	10.95	148.3	176.8	0.603	0.0205	262.1	20.21	239.9	328.7
6-Apr-02	2002	65	70.2	3.12	67.5	75.6	0.648	0.0328	108.3	7.29	102.1	137.1
11-May-02	2002	90	120	21.32	103.1	158.5	0.674	0.0265	178.1	32.37	146	293.2
1-Nov-02	2002	85	102	19.81	90	141	0.649	0.026	156.7	31.13	134.9	296.4
2-Apr-03	2003	34	37.8	3.96	35.2	45.5	0.739	0.0707	51.1	7.23	46.6	85.9
5-Nov-03	2003	93	105	5.86	99.6	114.8	0.59	0.0245	177.8	12.38	164.3	218.7
19-Mar-04	2004	94	116	12.47	104.8	137.2	0.598	0.031	193.5	23.13	168.8	271.2
21-Oct-04	2004	99	114	15.1	104.3	143.4	0.645	0.0241	177.1	24.3	157.9	278.2
13-Apr-05	2005	44	58.3	13.25	49.2	83.6	0.844	0.0644	69.1	16.51	55.5	136.1

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24-Mar-06	2006	121	131	8.18	125.1	146.4	0.685	0.0281	191.5	14.28	179.6	249
12-May-07	2007	27	28.8	2.45	27.5	33.8	1.634	0.2744	17.7	3.32	16.6	38.1
8-Nov-07	2007	23	26.8	8.03	23.7	43.4	0.72	0.061	37.2	11.55	32.3	102.8
19-Apr-08	2008	24	35.4	11.37	27.9	57.3	0.8	0.0992	44.3	15.13	32.6	108.3
28-Nov-08	2008	68	83.9	10.51	75.3	102.6	0.636	0.0313	131.8	17.72	114	194.2
19-Apr-09	2009	24	27.8	5	25	37.8	0.698	0.0687	39.8	8.13	35	80
3-Oct-09	2009	21	42	13.89	30.7	66.7	0.822	0.178	51.1	19.85	32.2	123.8
11-Apr-10	2010	11	13	2.44	11.6	17.8	1.59	0.4688	8.2	2.81	7	24.3
24-Oct-10	2010	24	28.6	3.15	26	34.2	0.568	0.0396	50.3	6.55	44.2	74.8
1-Apr-11	2011	26	27.7	2.77	26.4	33.4	0.769	0.0691	36	4.83	34	63.5
1-Oct-11	2011	86	129	21.89	108.8	165.6	0.58	0.0274	221.8	39.12	175.9	343.9

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Table A3.2. Density estimates for San Miguel Island, Nidever Canyon Grid. Trap Date is the date trapping of the grid began; Year is the year of trapping; Mt+1 is the number of distinct deer mice trapped and retained in the data set for analysis; Nhat is estimated deer mouse abundance on the trapping grid; Se(Nhat) is the standard error of the deer mouse abundance estimate; LCI(Nhat) and UCI(Nhat) are the lower and upper bounds of the 95% CI of the deer mouse abundance estimate; A(W) is the estimated area (hectares) sampled by the trapping grid; Se[A(W)] is the standard error of the estimated trapping area of the grid; Dhat is the estimated density of deer mice (mice/hectare) on the trapping grid; Se(Dhat) is the standard error of the estimated density of deer mice on the trapping grid; LCI(Dhat) and UCI(Dhat) are the lower and upper bounds of the 95% CI of the deer mouse density estimate on the trapping grid.

San Miguel Island, Nidever Canyon Grid

Trap Date	Year	Mt+1	Nhat	Se(Nhat)	LCI(Nhat)	UCI(Nhat)	A(W)	Se[A(W)]	Dhat	Se(Dhat)	LCI(Dhat)	UCI(Dhat)
7-Apr-93	1993	46	47.4	1.88	46.4	51.2	0.721	0.0358	65.8	4.17	63.9	89.1
12-Oct-94	1994	169	235	38.53	201.9	301.9	0.56	0.0238	419.5	70.97	341.2	652.2
12-Apr-95	1995	51	86.3	32.61	63.8	148.4	0.72	0.0651	119.9	46.41	81.1	305.9
11-Oct-95	1995	168	221	18.04	202.3	249	0.593	0.0319	371.9	36.33	324.2	475.1
23-Mar-97	1997	85	89.1	3.97	86.4	96.7	0.664	0.0208	134.2	7.3	129	166.6
9-Jul-97	1997	201	248	19.08	229	278.5	0.659	0.0325	375.8	34.36	333.8	479.5
20-Mar-98	1998	61	63.3	1.87	61.9	66.8	0.728	0.0647	87	8.15	84	135.7
26-Oct-98	1998	261	366	51.41	318.8	452.2	0.789	0.085	464.1	81.84	374.9	734.7
29-Jun-99	1999	159	208	26.4	184.4	252.9	0.627	0.0282	331.4	44.63	281	474.9
5-Apr-00	2000	52	60.8	6.79	55.6	73.3	0.734	0.0716	82.8	12.25	73.1	133.7
20-Oct-00	2000	166	186	8.9	177.1	200.2	0.562	0.016	330	18.42	308.4	387.5
5-May-01	2001	78	87.5	8.72	81.5	104.1	0.684	0.0352	128	14.34	116.7	187.9
30-Nov-01	2001	182	205	17.23	191.8	236.5	0.633	0.0158	323.9	28.37	296.9	427.9
8-May-02	2002	87	89.5	3.62	87.6	96.9	0.632	0.0211	141.6	7.43	138	181.7
14-Nov-02	2002	133	147	9.84	139.3	164.8	0.628	0.0198	234.4	17.32	217.8	297.6
7-May-03	2003	103	149	33.55	122.6	209.8	0.668	0.0269	222.8	50.98	172.9	405.9
23-Oct-03	2003	178	199	7.36	191.1	210.2	0.574	0.0138	346.1	15.3	326.3	390.2
25-Mar-04	2004	110	117	4.47	113.4	125	0.636	0.0205	184.1	9.18	175.6	218.5
13-Oct-04	2004	194	232	12.56	218.9	251.4	0.56	0.0149	414	24.98	379.9	482.7
15-Jun-05	2005	124	151	32.33	131.8	215	0.624	0.0219	241.3	52.44	205.1	478.4
16-Nov-05	2005	211	283	29.76	254	331.1	0.523	0.0126	541	58.37	465.5	708.9
11-May-06	2006	67	68.9	2.03	67.6	72.9	0.627	0.0268	109.9	5.71	107.1	140.8

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3-May-07	2007	9	12.1	3.29	10	18.5	0.753	0.2721	16	7.09	12.4	53.1
1-Nov-07	2007	58	58.7	1.01	58.2	60.8	0.685	0.033	85.7	4.38	84.7	114.4
1-May-08	2008	38	56.3	10.81	47.1	75.1	0.622	0.0616	90.6	19.5	70.2	157.1
6-Nov-08	2008	152	164	5.87	158.2	173.5	0.599	0.0152	273.1	12.02	260.1	313.1
16-Apr-09	2009	9	9				0.397		22.7			
17-Oct-09	2009	5	5				0.397		12.6			
12-Nov-09	2009	69	73.4	3.41	70.8	79.7	0.68	0.033	108	7.25	102.6	139.3
23-Apr-10	2010	37	62.2	32.68	44	127.9	0.781	0.0708	79.6	42.28	51.9	276.3
21-Oct-10	2010	39	51.1	21.6	41.6	95.7	0.597	0.0459	85.6	36.69	67.3	280.8
6-Apr-11	2011	47	48.9	2.27	47.5	53.4	0.729	0.0444	67.1	5.14	64.7	95.4
13-Oct-11	2011	83	112	20.08	95.6	147.7	0.577	0.0346	193.3	36.62	157.4	324.6

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Table A3.3. Density estimates for San Miguel Island, Willow Canyon Grid. Trap Date is the date trapping of the grid began; Year is the year of trapping; Mt+1 is the number of distinct deer mice trapped and retained in the data set for analysis; Nhat is estimated deer mouse abundance on the trapping grid; Se(Nhat) is the standard error of the deer mouse abundance estimate; LCI(Nhat) and UCI(Nhat) are the lower and upper bounds of the 95% CI of the deer mouse abundance estimate; A(W) is the estimated area (hectares) sampled by the trapping grid; Se[A(W)] is the standard error of the estimated trapping area of the grid; Dhat is the estimated density of deer mice (mice/hectare) on the trapping grid; Se(Dhat) is the standard error of the estimated density of deer mice on the trapping grid; LCI(Dhat) and UCI(Dhat) are the lower and upper bounds of the 95% CI of the deer mouse density estimate on the trapping grid.

San Miguel Island, Willow Canyon Grid

Trap Date	Year	Mt+1	Nhat	Se(Nhat)	LCI(Nhat)	UCI(Nhat)	A(W)	Se[A(W)]	Dhat	Se(Dhat)	LCI(Dhat)	UCI(Dhat)
14-Apr-93	1993	19	20.4	1.55	19.4	23.4	0.745	0.0928	27.3	3.98	25.6	49.9
11-Oct-95	1995	139	278	44.84	231.5	347.6	0.504	0.0387	551.4	98.31	415.7	818.9
27-Oct-96	1996	101	214	80.63	150	359.4	0.539	0.0298	396.2	150.97	246	931.7
23-Mar-97	1997	15	21.2	8.04	16.7	37.3	0.63	0.0782	33.6	13.33	25.1	96.7
10-Jul-97	1997	166	202	20.25	184.1	236.7	0.584	0.0242	345.6	37.51	304.6	469.4
14-Oct-97	1997	132	199	37.09	166.1	262.3	0.568	0.024	349.4	66.83	273.6	563.8
20-Mar-98	1998	16	20.4	4.91	17.4	30	0.482	0.0624	42.2	11.5	34.5	95.1
18-Oct-98	1998	286	589	123.28	468.4	788	0.479	0.015	1230	260.31	888.5	1970.6
29-May-99	1999	136	188	19.71	168.5	219.5	0.57	0.0422	330.1	42.26	277.3	455.3
11-Nov-99	1999	188	237	17.06	219.2	263.4	0.563	0.0225	419.7	34.58	373.9	517.3
13-Apr-00	2000	14	18.6	9.99	14.8	39.3	0.903	0.2232	20.6	11.86	15.8	89.4
7-Oct-00	2000	186	225	13.5	211.2	246.2	0.547	0.0201	411.6	28.95	373.5	493.6
19-Apr-01	2001	44	52.2	12.75	45.9	78.3	0.573	0.0408	91	23.12	78.3	208.8
6-Oct-01	2001	233	393	84.24	317.5	536.2	0.557	0.0171	705.2	152.6	526	1181.2
20-Apr-02	2002	69	91.5	13.33	80.1	114.7	0.573	0.0297	159.6	24.64	133	241.8
4-Oct-02	2002	156	179	9.68	169.6	194.7	0.614	0.0262	291.3	20.06	267.9	354.2
20-Apr-03	2003	69	83.7	8.65	76.3	98.7	0.688	0.0558	121.7	15.95	106.1	179
5-Nov-03	2003	146	279	35.46	240.4	332.2	0.485	0.0213	574.5	77.29	459.8	771.9
9-Apr-04	2004	116	139	16.36	125.8	168.3	0.537	0.0201	258.1	31.93	227.2	373.8
13-Oct-04	2004	245	388	112.02	303.3	594.2	0.537	0.0189	721.4	209.87	523.7	1496.1
13-May-05	2005	71	89.8	10.14	80.8	107.1	0.614	0.047	146.1	19.89	125.1	213.5
19-Nov-05	2005	89	279	71.94	207.1	393.5	0.515	0.0887	540.7	166.05	331	1028.3

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6-May-06	2006	114	119	3.09	116.2	124.2	0.499	0.0163	238.1	9.93	230.3	279.7
9-May-07	2007	19	21.3	3.58	19.5	28.6	1.095	0.1445	19.4	4.13	17.5	42.1
14-Nov-07	2007	47	57.2	9.49	50.7	75.3	0.663	0.0315	86.3	14.88	74	146.6
10-May-08	2008	47	60.7	12.6	52	84.7	0.694	0.0541	87.5	19.35	71.7	166.3
9-Nov-08	2008	75	86.2	11.79	78.7	109.2	0.539	0.0238	159.8	22.94	142.7	258.6
7-May-09	2009	60	76.2	9.95	67.8	93.7	0.576	0.0419	132.5	19.76	112.4	201.6
30-Sep-09	2009	68	87.8	10.58	78.3	105.8	0.576	0.0289	152.5	19.88	130.1	216.6
18-Apr-10	2010	15	22.1	8.41	17.1	38.8	0.825	0.0648	26.7	10.37	19.5	73.3
30-Oct-10	2010	23	29.5	8.66	24.8	47	0.605	0.0857	48.8	15.76	39.3	125.6
17-Mar-11	2011	4	5.5	3.04	4.3	11.8	0.397	0	13.9	7.66	10.4	56
28-Sep-11	2011	64	98.6	19	81.9	131.2	0.552	0.0295	178.6	35.65	138.1	292.8

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