Assessing Numbers of Subsamples per Sampling Unit to Monitor the Feeding Sign Index of Abert's Squirrel, San Juan National Forest, Colorado

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INTRODUCTION

Background

The San Juan National Forest (SJNF) in southwestern Colorado consists of the Columbine, Dolores, and Pagosa Springs Ranger Districts. Abert's squirrel (*Sciurus aberti*) were designated as a management indicator species (MIS) in the SJNF Land and Resource Management Plan in 1983 and retained in the 1992 amendment (Ghormley 2005). The SJNF selected Abert's squirrel as an MIS because of the species obligate association with ponderosa pine (*Pinus ponderosa*), which they depend on for food and cover (Keith 2003).

Objective and Purpose of Monitoring

The objective of the SJNFs Abert's Squirrel Monitoring Plan is "to provide a consistent, rigorous framework to evaluate trend in the habitats and populations of Abert's squirrel on the SJNF (Ghormley 2005)." The purpose of monitoring squirrels under the plan is to evaluate population trends associated with the amount and quality of habitat over time as described in the 1982 planning regulations defining MIS (36 CFR 219.19; Ghormley 2005). Thus, monitoring includes assessing trend in ponderosa pine habitats and squirrel populations.

The objectives of my evaluation were to (1) assess the number of subsamples needed to evaluate the feeding sign index used to monitor Abert's squirrel populations on the SJNF, and (2) provide a 3-year analysis (2005–2007) of trend in the feeding sign index to assess whether the current monitoring program for Abert's squirrel on the SFNF is sufficiently robust to detect changes in the feeding sign index.

METHODS

Abert's squirrel monitoring data were collected from 2005–2007 on the Columbine, Dolores, and Pagosa Springs Ranger Districts of the San Juan National Forest in southwestern Colorado. All statistical analyses were conducted with SAS statistical software (SAS Institute 2003).

Sampling Methods

Elson (2004) recommended sampling approximately 2% of the suitable habitat in a population to evaluate population trends in Abert's squirrel. On the SJNF, this equates to 4,618 acres, which are approximately evaluated in 4,080 acres of plot area (68 plots × 60 acres).

Sixty-acre plots are the sampling units in the Abert's squirrel sampling design. Feeding evidence, measured in 1-m^2 sampling quadrats systematically placed within each 60-acre plot are the elements measured in the design. Sampling units were stratified into 2 strata based on habitat structural stage (HSS), which reflects suitability of Abert's squirrel habitat. Optimal strata were classified as larger structural size trees (HSS 4B, 4C, and 5), whereas marginal strata consisted of smaller sized trees (HSS 4A). Poor-quality habitat (HSS 2, 3A, 3B, and 3C) within the ponderosa pine cover type represents a third stratum, which was not incorporated into the 2005–2007 sampling effort (Ghormley 2005).

In 2005, Forest Service employees randomly placed 68, 60-acre sampling plots (sampling units) among the 3 Ranger Districts to collect feeding sign information for Abert's squirrels. Data were collected at each sample plot in spring (March through early June) 2005, 2006, and 2007.

Within each sampling unit, 256, 1-m^2 subsampling quadrats were placed along 8 transects, with 32 subsamples per transect. In some cases subsample locations were discarded to eliminate the potential bias associated with non-ponderosa pine habitat (e.g. large openings); this resulted in an adjusted (lower) number of subsample locations in many sampling units. Transects were placed parallel to one another, 70 m apart with subsample quadrats placed 17.5 m along each transect starting at the 0-m mark. Each 60-acre sampling plot thus represented an independent observational unit from which fresh feeding sign information was obtained.

Parameter of Interest

The parameter of interest for monitoring trends in Abert's squirrel populations was the proportion of subsamples in each sampling unit (60-acre plot) with presence of fresh Abert's squirrel feeding sign ($\hat{P}$). This proportion provides an index to relative abundance of squirrels that can be monitored for trend over time. The relationship between the index and abundance of Abert's squirrel has been developed (Dodd et al. 1998) and validated in northern Arizona (Dodd et al. 2006), but has not been validated for squirrels on the SJNF.

Fresh feeding sign is defined as green (or mostly green) clipped needle clusters, white peeled twigs, red or orange cone cores, and well-defined fungi digs without litter or soil obscuring the hole (Ghormley 2005). Feeding sign in 1-m^2 subsampling quadrats was denoted as a "1" to indicate presence or a "0" to indicate absence, which was then used to compute $\hat{P} = \left(\frac{\text{feeding sign counts}}{\text{adjusted sample points}} \right)$.

Objective 1

Measuring 256 subsamples on each 60-acre sampling unit requires significant field effort. The San Juan National Forest is interested in evaluating the cost/benefit of this level of sampling. To address Objective 1, I evaluated the number of subsamples that need to be collected to provide similar results to those from sampling units with 256 subsamples based on subsampling intensities of 25, 50, 75, 100, 125, 150, 175, 200, and 225.

I based my evaluation on 3 criteria, using 1,000 Monte Carlo simulations of sampling without replacement to estimate the proportion of subsamples with presence of Abert's squirrel sign ($\hat{P}$). The Monte Carlo resampling method is similar to bootstrapping, but uses subsampling without replacement (Efron and Tibshirani 1993). This resampling method was used because in actual practice a data collector would not consider resampling each subsample after it has been sampled (sampling with replacement), but instead would sample a subsample quadrat and then sample the next one, etc. Because the data did not follow a normal distribution, I used bootstrapped (with 2000 resamples), bias-corrected and accelerated (BCa) confidence intervals as suggested by Efron and Tibshirani (1993) to compute approximate 95% confidence intervals.

True $\hat{P}$ is the proportion of subsamples in each sampling unit with feeding sign, averaged within each strata and year combination. Each criterion compared Monte Carlo simulated estimates for each subsample size to true $\hat{P}$. Criteria 1 and 2 are related in that they both assess proportions of simulated estimates that are within percentages of the true $\hat{P}$ for each year and strata; however, Criterion 1 is more restrictive as it only evaluates the percentage of simulated estimates in each subsample size that lie within ± 10% true $\hat{P}$. Consequently, Criterion 1 was most important in determining adequate subsample size. I used Criteria 2 and 3 to provide confirmatory evidence for identified subsampling intensities within each stratum.

Criterion 1 assessed when 95% of Monte Carlo estimates occurred within ± 10% of true $\hat{P}$, which was computed as the division of the Monte Carlo estimates by true $\hat{P} \times 100$. Criterion 2 evaluated when 100% of each of the 1,000 Monte Carlo simulation estimates for each subsample were within the 95% confidence interval of true $\hat{P}$. Criterion 3 evaluated potential bias, which was computed as estimated $\hat{P}$ – true $\hat{P}$, and was assessed by plotting these errors in boxplots. This final criterion provided a way to evaluate whether a reduction in subsample size leads to increased bias in simulated estimates of the Abert's squirrel feeding sign index.

Objective 2

A fundamental question guiding the analysis of Objective 2 was whether one can assess trends over years in the feeding sign index $\hat{P}$ for Abert's squirrel given the current monitoring design on the SJNF. I used a generalized linear mixed model with repeated measures to evaluate trend in $\hat{P}$. The dependent variable (Y) for this model was $\hat{P}$ and predictor variables (X) were year, strata, and the year × strata interaction term (i.e., $\hat{P}$ = year strata year × strata). The data from each sampling unit were not normally distributed (data followed an exponential distribution) and were correlated from year-to-year. Hence, the statistical code was specified to follow the exponential distribution and use an autoregressive Type 1 time series covariance structure to provide the best model fit to the data.

RESULTS

Of the 68 sampling units, 13 (4 marginal habitat; 9 optimal habitat), 30 (15 marginal habitat; 15 optimal habitat), and 25 (13 marginal habitat; 12 optimal habitat) were distributed on the Columbine, Dolores, and Pagosa Springs Ranger Districts, respectively (Table 1). In total, optimal strata represent 36 of the 68 (53%) and marginal 32 of the 68 (47%) sampling units. Removing subsamples in non-ponderosa pine habitat limited sampling units to as few as 214 subsamples (mean = 249; mode = 256; Table 1).

Proportion of Abert's squirrel sign in subsamples ($\hat{P}$) was 0.014 in 2005, 0.030 in 2006, and 0.036 in 2007 in marginal sampling units and 0.037 in 2005, 0.032 in 2006, and 0.045 in 2007 in optimal sampling units (Figure 1). The estimate for marginal strata in 2005 was lower than all other year × strata estimates of $\hat{P}$ (Figure 1).

Objective 1

From 2005 to 2007 for the marginal strata, simulated estimates were within 10% of the true $\widehat{P}$ at a subsample size of 200 (range, 150–200 subsamples; Table 2). Across years for the optimal strata, simulated estimates were within 10% of the true $\widehat{P}$ for Criterion 1 at a subsample size of 150 (range 125–150 subsamples; Table 2). For both strata, Criterion 2 further supported the subsample assessment from Criterion 1 because 100% of the simulated estimates of $\widehat{P}$ were within the BCa 95% confidence intervals for 200 subsamples in the marginal strata (Figure 2) and 150 subsamples in the optimal strata (Figure 3) as compared to sampling 256 subsamples in Abert's squirrel sampling units. For both strata, as subsample sizes decrease, there is no evidence for potential bias (Figures 4 and 5).

Objective 2

There was a significant year, strata, and year × strata interaction in trend of $\widehat{P}$ (Table 3). Tukey's HSD multiple comparison tests indicated that parameter estimates for marginal strata in 2005 differed from every other year × strata interaction. More importantly there was no significant effect of time for optimal sampling units ($F_{2,132} = 1.79$, $P = 0.343$), but there was a significant effect of time in marginal sampling units ($F_{2,\ 132} = 9.63$, $P < 0.001$). Estimates of $\widehat{P}$ for marginal strata were 2.1- and 2.6-times greater in 2006 and 2007, respectively, than in 2005 (Figure 1).

DISCUSSION

Objective 1

Through comparing simulation results against 3 criteria I was able to determine subsample sizes for marginal and optimal strata over 3 years that provided estimates of $\widehat{P}$ within reasonable levels currently achieved by sampling 256 subsamples in Abert's squirrel sampling units. My analyses indicate that similar results can be obtained through fewer subsamples at each Abert's squirrel sampling unit. Ultimately, changing the monitoring program to accommodate fewer subsamples will reduce sampling costs incurred by the San Juan National Forest to evaluate the feeding sign index in Abert's squirrel. [1]

Based on my results, I would suggest the San Juan NF could achieve an acceptable level of accuracy by employing 150 subsamples in optimum habitat and 200 subsamples in marginal habitat. This would represent a 42% reduction in effort in optimal habitat and a 22% reduction in effort in marginal habitat. The current design is clearly capable of detecting changes in

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[1] A further evaluation would examine numbers of transects instead of numbers of subsamples. Rather than randomly sample from among the 256 subsamples at each sampling units, as was done with the Monte Carlo simulations, one would follow an analysis strategy that is more in line with field sampling implementation. For instance, the Monte Carlo simulations would be based on numbers of transects or numbers of subsamples along transects to determine if fewer transects or subsamples along transects would achieve estimates within defined levels of current estimates.

squirrel abundance, by strata, over a 3 year monitoring horizon as demonstrated by the significant year effect in marginal habitat in 2005 as detected in the analysis for Objective 2.

Reducing sampling effort as suggested above, would somewhat decrease the precision of the estimate for each sampling unit. However, the decrease in precision would be small as demonstrated by the Monte Carlo simulations.

Objective 2

My results indicate that the current monitoring program for Abert's squirrel on the San Juan National Forest is designed with sufficient rigor to detect changes in estimates of $\widehat{P}$ for Abert's squirrel in both strata over at least a 3-year span. My analysis suggested an increase in squirrel abundance in marginal habitat from 2005 to 2007 while abundance appeared to remain relatively constant in higher quality habitat. This result would be expected given the drought experienced on the SJNF and the expectation that habitat quality in marginal habitat would be influenced most strongly during such an event.

CONCLUSIONS

Objective 1

- For marginal strata, reduce sampling to 200 subsamples per sampling unit, which will reduce sampling effort by 22% per sampling unit

- For optimal strata, reduce sampling to 150 subsamples per sampling unit, which will reduce sampling effort by 41% per sampling unit

Objective 2

- Estimates of $\widehat{P}$ in the marginal strata in 2005 were less than estimates for all other strata and year combinations

- The current protocol of 68 sampling units in 2 strata, across 3 ranger districts is sufficiently robust to detect temporal changes in estimates of $\widehat{P}$ for Abert's squirrel

MANAGEMENT RECOMMENDATIONS

Objective 1

Implementing fewer subsamples in the SJNF Abert's squirrel monitoring program will require managers to randomly or systematically select subsampling locations to remove from each sampling unit. Systematic removal of subsample locations in marginal sampling units would entail removing every fifth sampling location. In practice, this would result in sampling 6 fewer subsample locations on each transect for an overall reduction of 48 subsamples per 60-acre sampling unit. Systematic removal of subsamples in optimal sampling units would require removing every second subsample on 4 transects (64 subsamples) and every third subsample on

4 transects (40 subsamples) for an overall reduction of 104 subsamples per 60-acre sampling unit. The process in removing subsamples should be standardized as much as possible; however, there will likely be differences in subsample locations that are removed due to non-habitat locations in some sampling units.

Decisions regarding reduction of subsampling should ultimately include an evaluation of the impact on field costs. The recommended reductions in subsampling represent a guide to reduce the cost of field efforts at each sample site. Savings in time accumulated by reducing the number of subsamples could be used to increase the number of sites sampled or to reduce the overall cost of monitoring Abert's squirrel. In either case, savings in field cost depend on whether the reductions in subsamples can be translated to reduced time sampling in the field. Therefore, I suggest that the Forest determine whether reductions in subsampling can result in more sites being visited during the average field day.

Objective 2

My analysis indicates that there are sufficient sampling units in each stratum to maintain a robust Abert's squirrel monitoring program on the SJNF. The monitoring program was designed to achieve sufficient power to detect 10% annual declines in $\hat{P}$ over a 5-year monitoring period (Ghormley 2005). Preliminary analysis after 3 years suggests the current number of sampling units in each stratum is sufficient to detect trends, over this time horizon, in each stratum.

ACKNOWLEDGMENTS

Greg Hayward, Rocky Mountain Regional Wildlife Ecologist, provided direction for this assessment. Gretchen Fitzgerald of the SJNF provided funding and squirrel monitoring data. I thank the biologists who collected and summarized the Abert's squirrel feeding sign monitoring data on the San Juan National Forest. In particular, I thank Laurie S. Porth, Archivist/Statistician for the Statistics Unit, U.S. Forest Service Rocky Mountain Research Station, for conducting the statistical analyses.

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Table 1. Subsamples considered in simulations of $\widehat{P}$ for Abert’s squirrel by ranger district and strata, San Juan National Forest, Colorado, 2005–2007.

Ranger District	Sampling Unit	Strata	Subsamples		
			Removed	Remaining	Non-habitat (%)
Columbine	Bear Creek	Marginal	0	256	0.0
Columbine	First Notch	Marginal	0	256	0.0
Columbine	Middle Sauls Creek	Marginal	19	237	7.4
Columbine	Sawmill Canyon	Marginal	7	249	2.7
Columbine	Chris Park	Optimal	13	243	5.1
Columbine	Dry Lake Reservoir	Optimal	0	256	0.0
Columbine	East Creek	Optimal	0	256	0.0
Columbine	Indian Creek	Optimal	4	252	1.6
Columbine	Junction Creek East	Optimal	0	256	0.0
Columbine	Peterson Gulch	Optimal	0	256	0.0
Columbine	Sauls Creek	Optimal	0	256	0.0
Columbine	Shamrock	Optimal	2	254	0.8
Columbine	Upper Bull Canyon	Optimal	0	256	0.0
Dolores	Aaron Reservoir	Marginal	7	249	2.7
Dolores	Boggy Draw Road	Marginal	25	231	9.8
Dolores	Colt Reservoir	Marginal	13	243	5.1
Dolores	Cow Canyon	Marginal	32	224	12.5
Dolores	Doe Canyon	Marginal	42	214	16.4
Dolores	Haycamp Point	Marginal	0	256	0.0
Dolores	Hoppe Point	Marginal	17	239	6.6
Dolores	Horsetooth Reservoir	Marginal	0	256	0.0
Dolores	Narraguinnep	Marginal	28	228	10.9
Dolores	Smoothing Iron	Marginal	28	228	10.9
Dolores	Spruce Water Canyon	Marginal	27	229	10.5
Dolores	Trimble Point	Marginal	3	253	1.2
Dolores	Waterhole	Marginal	2	254	0.8
Dolores	Wild Bill	Marginal	3	253	1.2
Dolores	Wolf Den	Marginal	7	249	2.7
Dolores	Bean Canyon	Optimal	0	256	0.0
Dolores	Bean Reservoir	Optimal	0	256	0.0
Dolores	Big Water	Optimal	14	242	5.5
Dolores	Dunham Point	Optimal	1	255	0.4
Dolores	East Lost Canyon 2	Optimal	10	246	3.9
Dolores	Italian Canyon	Optimal	0	256	0.0
Dolores	Joe Moore	Optimal	10	246	3.9
Dolores	Lake Clydia	Optimal	40	216	15.6
Dolores	Little Bill	Optimal	2	254	0.8
Dolores	Little Buck Canyon	Optimal	3	253	1.2
Dolores	McPhee Park	Optimal	0	256	0.0

Table 1. Continued.

Ranger District	Sampling Unit	Strata	Subsamples		
			Removed	Remaining	Non-habitat (%)
Dolores	Millwood	Optimal	2	254	0.8
Dolores	Plateau	Optimal	38	218	14.8
Dolores	Trail Canyon	Optimal	2	254	0.8
Dolores	Upper Five Pine	Optimal	0	256	0.0
Pagosa Springs	Burns Canyon	Marginal	0	256	0.0
Pagosa Springs	Devil Mountain	Marginal	0	256	0.0
Pagosa Springs	East Fork Piedra River	Marginal	0	256	0.0
Pagosa Springs	Echo	Marginal	0	256	0.0
Pagosa Springs	Fawn Gulch	Marginal	0	256	0.0
Pagosa Springs	Hotz Spring	Marginal	0	256	0.0
Pagosa Springs	Monument Park	Marginal	12	244	4.7
Pagosa Springs	Rito Blanco	Marginal	0	256	0.0
Pagosa Springs	Sheep Cabin Spring	Marginal	0	256	0.0
Pagosa Springs	South Laughlin	Marginal	0	256	0.0
Pagosa Springs	Stollsteimer	Marginal	0	256	0.0
Pagosa Springs	Treasure	Marginal	3	253	1.2
Pagosa Springs	Turkey Mountain	Marginal	0	256	0.0
Pagosa Springs	Ice Cave Ridge	Optimal	20	236	7.8
Pagosa Springs	Kenney Flats A	Optimal	0	256	0.0
Pagosa Springs	Kenney Flats C	Optimal	0	256	0.0
Pagosa Springs	Kenney Flats H	Optimal	0	256	0.0
Pagosa Springs	Lower Horse Creek	Optimal	0	256	0.0
Pagosa Springs	Lower Valle Seco	Optimal	0	256	0.0
Pagosa Springs	Piedra	Optimal	0	256	0.0
Pagosa Springs	Turkey Springs A	Optimal	18	238	7.0
Pagosa Springs	Turkey Springs E	Optimal	0	256	0.0
Pagosa Springs	Turkey Springs G	Optimal	0	256	0.0
Pagosa Springs	Turkey Springs I	Optimal	0	256	0.0
Pagosa Springs	Turkey Springs K	Optimal	0	256	0.0

Table 2. Results of Criterion 1 used to determine number of subsamples needed to estimate $\widehat{P}$ for Abert's squirrel on the San Juan National Forest, Colorado, 2005–2007. Results are based on 1,000 Monte Carlo simulations by subsample size to estimate the proportion of subsamples with presence of Abert's squirrel sign ($\widehat{P}$). Criterion 1 assessed whether ≥95% of Monte Carlo estimates occurred within ± 10% of the true $\widehat{P}$, which was computed as the division of the Monte Carlo estimates by true $\widehat{P}$ × 100 and highlighted in gray.

		Subsamples								
Year	Strata	25	50	75	100	125	150	175	200	225
2005	Marginal	27	38	56	61	71	78	91	97	100
2006	Marginal	33	55	69	79	88	95	98	100	100
2007	Marginal	39	60	72	84	93	97	99	100	100
2005	Optimal	47	69	79	88	95	98	100	100	100
2006	Optimal	49	61	74	82	93	96	99	100	100
2007	Optimal	51	70	82	92	97	99	100	100	100

Table 3. Generalized linear mixed model results for Type III tests of fixed effects to evaluate trend in the proportion of subsamples in sampling unites with Abert's squirrel feeding sign ($\hat{P}$), San Juan National Forest, Colorado.

Effect	Numerator DF	Denominator DF	*F*	*P*
Strata	1	66	4.96	0.029
Year	2	132	6.29	0.003
Strata × Year	2	132	5.60	0.005

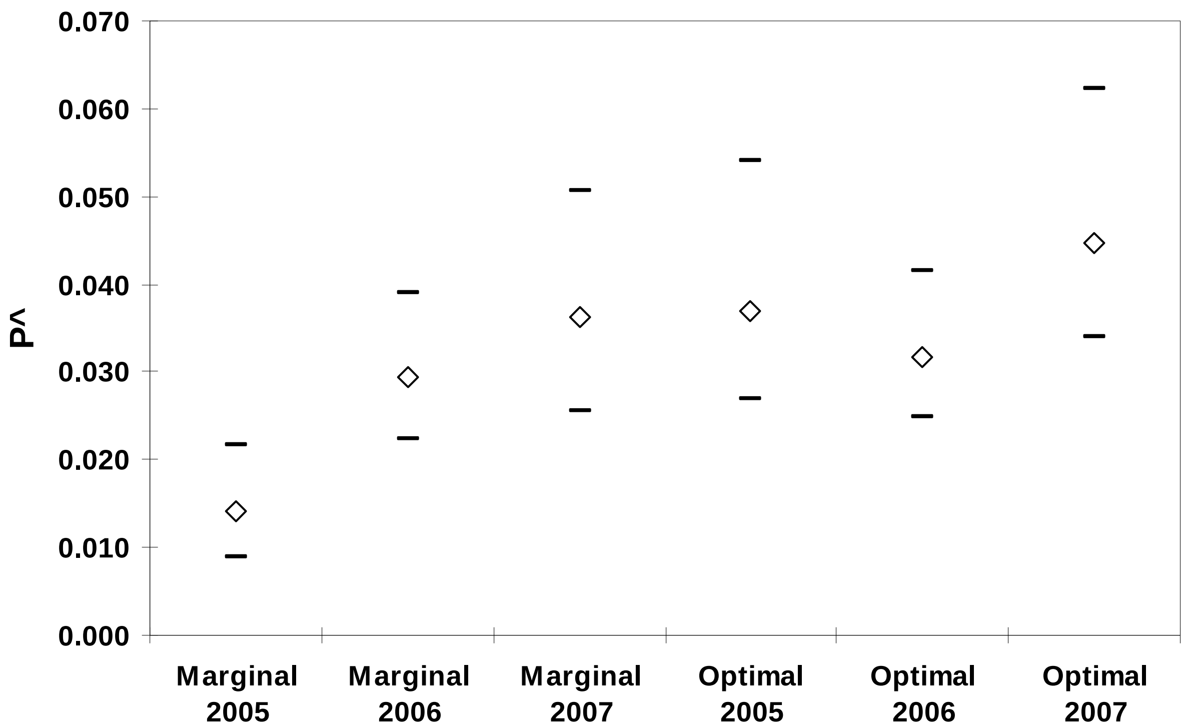
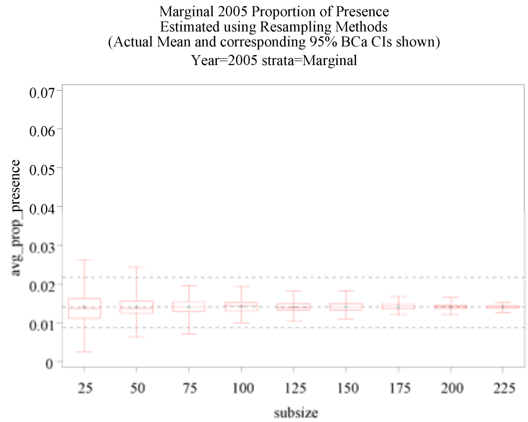
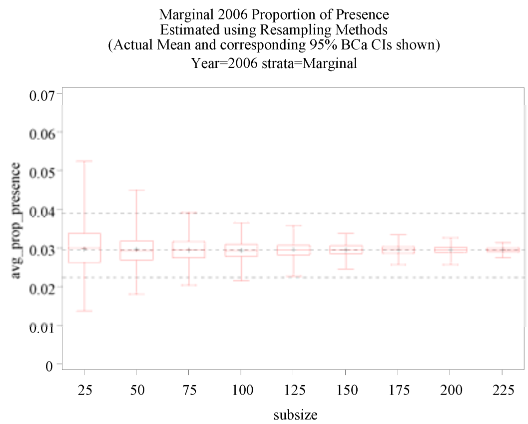


Figure 1. Estimated proportion of squirrel feeding sign in sampling units ($\widehat{P}$ ± 95% BCa confidence intervals) for marginal and optimal strata, San Juan National Forest, Colorado, 2005–2007. Proportions within each sampling unit were averaged across strata (Marginal, n = 32; Optimal, n = 36). Hollow diamonds are point estimates and dashes are 95% BCa confidence intervals. Confidence intervals represent nonparametric Bias-Corrected and accelerated bootstrap confidence intervals approximated using 2000 resamples (Efron and Tibshirani 1993).





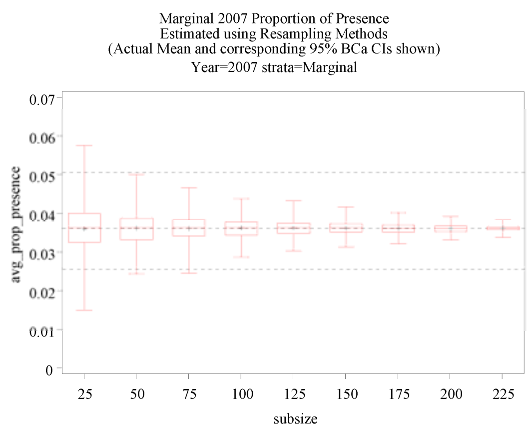


Figure 2. Criterion 2–Monte Carlo simulation estimates for each subsample within the 95% BCa confidence interval (CI) of true $\widehat{P}$ in Abert's squirrel feeding sign index for sampling units in marginal strata in 2005 (top), 2006 (middle), and 2007 (bottom). The middle dashed line is the average true $\widehat{P}$ and the 95% BCA confidence interval limits are upper and lower dashed lines.

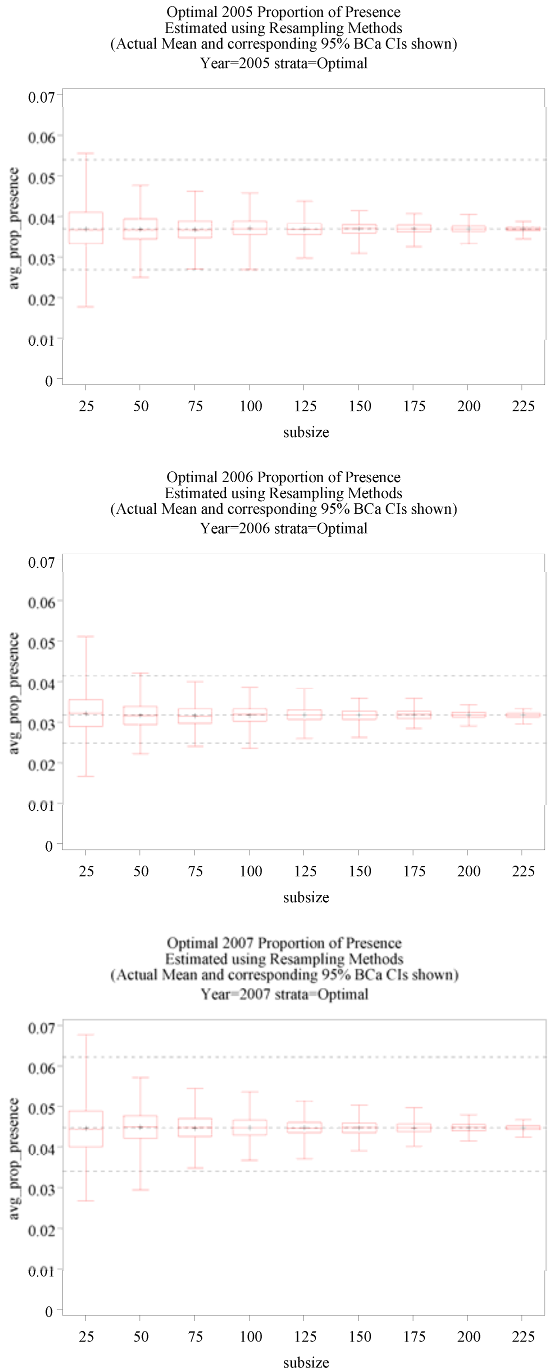
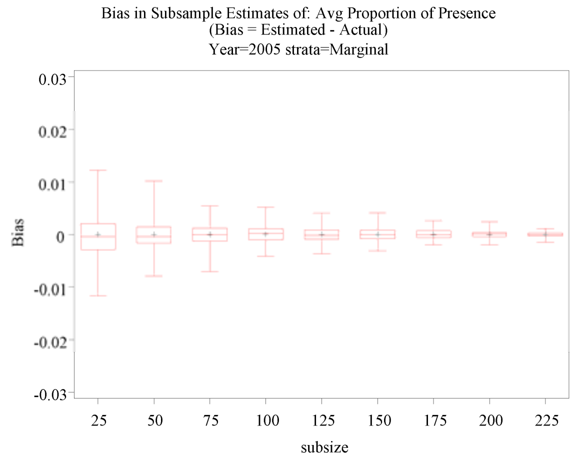
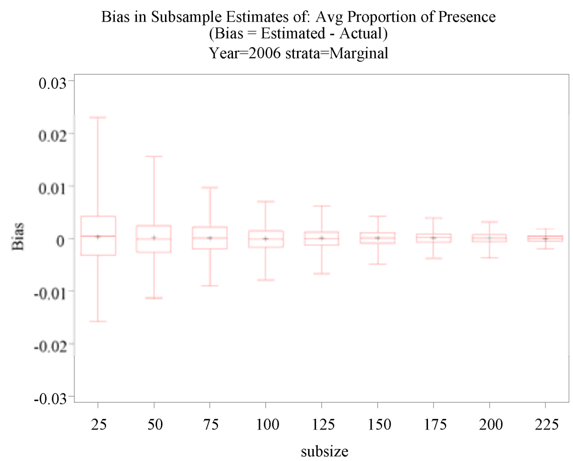


Figure 3. Criterion 2–Monte Carlo simulation estimates for each subsample within the 95% BCa confidence interval (CI) of true $\widehat{P}$ in Abert's squirrel feeding sign index for sampling units in optimal strata in 2005 (top), 2006 (middle), and 2007 (bottom). The middle dashed line is the average true $\widehat{P}$ and the 95% BCA confidence interval limits are upper and lower dashed lines.





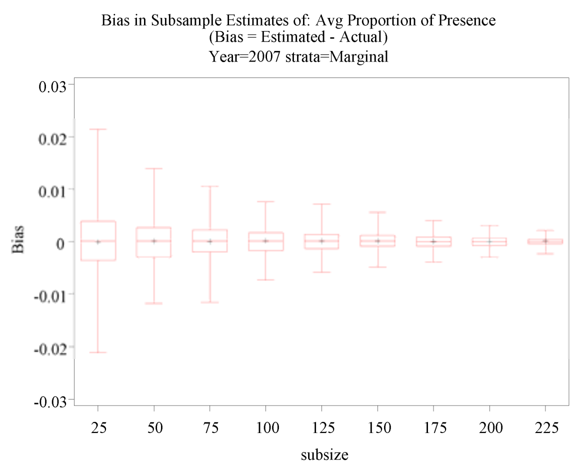
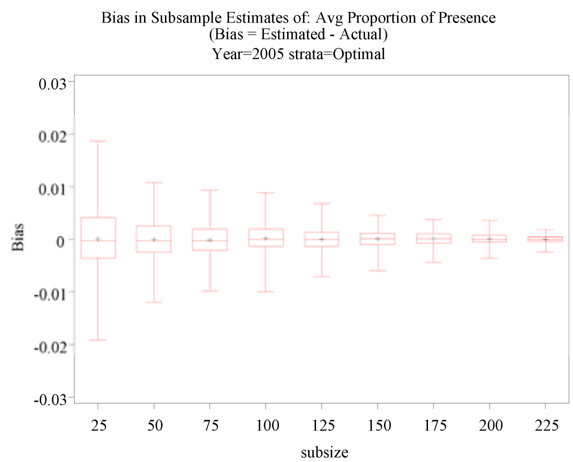
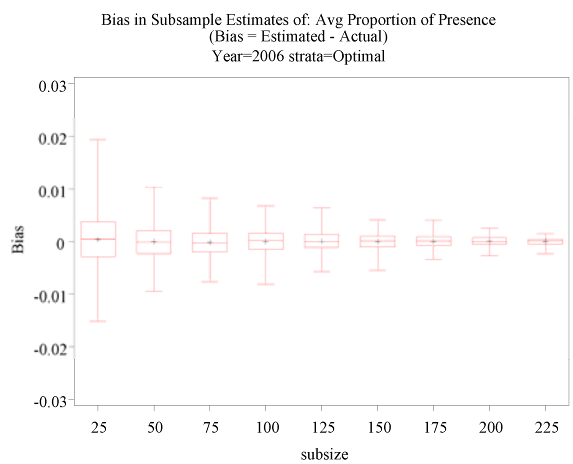


Figure 4. Assessment of potential bias in Abert's squirrel feeding sign index for sampling units in marginal strata in 2005 (top), 2006 (middle), and 2007 (bottom). Bias was computed as estimated proportion of subsamples with presence of feeding sign ($\widehat{P}$; through 1,000 Monte Carlo simulations) minus the actual or "true $\widehat{P}$ " proportion of subsamples with presence of feeding sign.





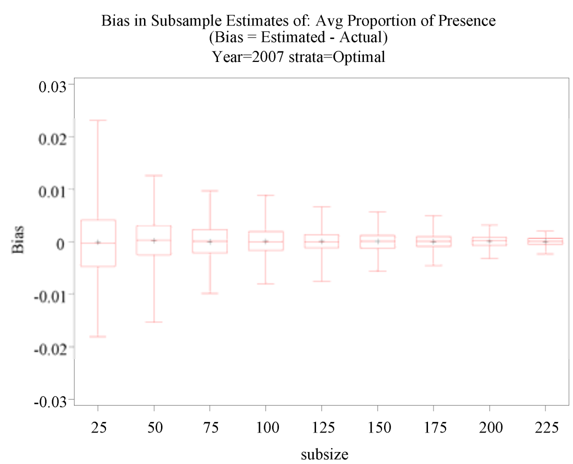


Figure 5. Assessment of potential bias in Abert's squirrel feeding sign index for sampling units in optimal strata in 2005 (top), 2006 (middle), and 2007 (bottom). Bias was computed as estimated proportion of subsamples with presence of feeding sign ($\widehat{P}$; through 1,000 Monte Carlo simulations) minus the actual or "true $\widehat{P}$ " proportion of subsamples with presence of feeding sign.