EVALUATION OF TIME-LAPSE PHOTOGRAPHY TO ESTIMATE POPULATION PARAMETERS

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Desert Bighorn Counc. Trans. 35:5–8.

Abstract: We investigated the utility of time-lapse photography to provide population estimates and lamb populations. We compared 2 methods of time-lapse data analysis: group sampling and frame sampling. We failed to reject the null hypothesis that population estimates and lamb:ewe ratios from time-lapse and direct observation sampling were the same.

Key words: mark-recapture, Mojave Desert, mountain sheep, Ovis canadensis, population estimation, techniques, time-lapse photography.

Time-lapse cameras have been considered an effective tool to determine whether a particular water source is being used by mountain sheep (Davis and Bleich 1980), classify the age and sex of mountain sheep (Helvie 1972, Constantino 1973), and determine mountain sheep drinking times (Constantino 1973, Campbell and Remington 1979). In 1972, Constantino (1973) conducted a census of mountain sheep on the Desert National Wildlife Range, Nevada, using time-lapse cameras. The time-lapse cameras recorded "at least 85%" of the population as determined by estimates made from field observations, lamb counts, helicopter counts, and "other" census methods. However, his methodology was not detailed. Wehausen and Hansen (1986) attempted to use time-lapse cameras to aid in mark-recapture (mark-and-sample; MS) population estimates of desert-dwelling mountain sheep. Various problems precluded this intended use; however, they were able to clearly identify marked individuals. Our objective was to compare time-lapse camera and direct observational sampling for generating MS population estimates and lamb:ewe ratios.

In 1986, the California Department of Fish and Game (CDFG) began field studies of the mountain sheep population in the vicinity of Old Dad Mountain and the Kelso and Marl mountains. Between September 1986 and September 1989, 17 ewes and 22 rams were marked with collars. Ground surveys and helicopter censuses were conducted prior to and during the study period to obtain MS estimates of the population and to determine recruitment rates (Wehausen 1990). These estimates provided the background information against which the time-lapse camera estimates for this study were evaluated.

Inherent to time-lapse camera sampling (TLS) is the potential problem of time-gaps between photographs. In a standard analysis of sheep groups visiting water, only the minimum group size and composition based on maximum numbers of identified individuals in each age and sex class can be determined. Because ewes were more numerous in most groups and more homomorphic, they were potentially more difficult to identify individually than were other sex and age classes. This could lead to overestimates in ratios of lambs to ewes. Collared ewes and rams were always identifiable as such; therefore, the same problem might occur in ratios of collared to uncollared animals. Because of these potential problems, a second analytical approach also was pursued wherein individual photographs (i.e., frames) were used as sampling units. This approach had a problem of non-independence of successive frames sampled, because the same individuals were sampled multiple times during each visit to water. Nevertheless, it was pursued to investigate potential relative bias in methods of analysis.

We thank M. H. Fusari for reviewing an earlier manuscript, and the University of California, Granite Mountain Reserve for providing logistic support during this study. The Society for the Conservation of Bighorn Sheep, San Bernardino County Fish and Game Commission, and T. L. Russi provided time-lapse cameras. R. T. Bowyer and M. Ananda provided useful comments on the manuscript. Work by the first author was funded in part by the Hansen-Welles Memorial Fund of the Desert Bighorn Council, a President's Undergraduate Fellowship from the University of California, and grants from the University of California, Santa Cruz. Work by the second author was supported by the California Department of Fish and Game through a contract (FG 7468-A1) with the University of California, White Mountain Research Station. Partial funding for helicopter surveys and equipment was provided by grants to the third author from the Boone and Crockett Club, Foundation for North American Wild Sheep, and the National Rifle Association, through the Institute of Arctic Biology at the University of Alaska, Fairbanks.

STUDY AREA

The study area was located in the eastern Mojave Desert approximately 30 km southeast of Baker, San Bernardino County, California. Old Dad Mountain is a steep, limestone massif, while the other ranges are predominately granitic in origin and much less precipitous (Bleich et al. 1990a). Elevations vary from 550 to 1,450 m. Vegetation is typical of the Mojave Desert at these elevations (Martens and Baldwin 1983).

Six water sources in the study area were considered for TLS. Of the 2 springs located in the Marl Mountains, sheep sign was found only at Jackass Spring in the summer of 1988; consequently, we monitored this spring during the 1989 study period. The other water sources monitored are artificial water catchments used by sheep. One of these catchments (Kelso Peak Guzzler) is located near Kelso Peak in a rolling hills area of the mountain complex. The other 3 catchments (Kerry Guzzler, Main Peak Guzzler, North Guzzler) occur at Old Dad Mountain and are located in steep, rocky terrain.

METHODS

Time-lapse cameras similar to those described by Montalbano et al. (1985) were used to monitor the water sources used by sheep. The units varied in manufacturer, optics, circuitry, and power source. Each camera had a photocell that turned the unit off at night and back on at daybreak. The cameras were set to expose 1 frame of super 8-mm color film (Kodak Ektachrome 160) every 60 seconds. Cameras were positioned as described by Constantino (1974).

We conducted TLS from 20 July to 7 September 1988 and 22 June to 27 September 1989. Films were changed every 3–7 days. During 1988, the field of view (or area photographed) for each camera was determined to be too wide for ideal classification of sheep. The field of view was decreased in 1989 and set so that only sheep within a few meters of the water sources were photographed.

The 1988 study period was preliminary, and monitoring was attempted only at the 4 artificial water catchments. The theft of a camera unit from the North Guzzler precluded any useful monitoring of that water source during 1988. This was a major impediment to sampling, because this guzzler received substantial use by ewe groups that summer;

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consequently, the 1988 data were analyzed using only the group sampling method described below.

The number of water sources monitored was increased by the addition of Jackass Spring in 1989. However, the North Guzzler dried-up shortly after 26 June, and monitoring of that water source was discontinued. This was not considered a problem, because sheep distributed around the North Guzzler subsequently shifted to the 2 southern guzzlers. One of these (Kerr Guzzler) dried-up about 6 July, and monitoring was suspended until 21 July, after a local rain shower recharged the guzzler.

Each film was analyzed with a variable speed projector and run through the projector twice. In the first viewing, films were projected at 6 frames/second. Those frames in which objects could be clearly distinguished were timed by stop watch. Using the projection rate, the number of usable frames (uf) per film was calculated. We recorded 60,680 uf for 1988 and 131,897 uf for 1989. In the second viewing, slower projection speeds (often only 1 frame/several minutes) were used to identify the mountain sheep photographed. Sheep were classified by sex and age as: adult and yearling females; lambs; and rams by horn size (class 1 [yearling], class 2, and classes 3 and 4 combined [Geist 1971]). Unidentified sheep also were recorded, but were discarded in the final analysis. Sheep in each category were tallied by water source and used to note differential use of water sources. Days could be determined by changes in lighting on the film, and data were recorded on a daily basis.

We used 2 analytical approaches: group sampling and frame sampling. Group sampling was an analysis of the identity and minimum size of the sheep groups photographed. Sheep groups generally were defined by separation in time, but this determination was subjective. If the viewer recognized that the same individuals were coming into water repeatedly over an extended period, possibly separated by many minutes, then those animals were classified as a single group (thus a single visit). Similarly, if the viewer clearly determined that 1 group of sheep had left and that a different group had come to water within minutes of the first group's dispersal, those were classified as 2 separate groups. Classified sheep were used to determine summer lamb:ewe ratios. Collared sheep were recorded to provide proportions of ewes and rams collared, from which MS population estimates were obtained.

Frame sampling used frames as sampling units and produced 2 data sets: sheep/frame and necks/frame. Sheep/frame was comprised of classified mountain sheep/uf. Each uf containing mountain sheep was carefully analyzed and all sheep photographed on the frame were classified. As discussed previously, each frame was treated as an independent sample; thus, information from preceding frames was not used to identify sheep in the succeeding frames. In this analysis, each identifiable individual photographed/frame was tallied, by sex and age class, as 1 sheep-frame. This produced ratios of lamb frames to adult and yearling ewe frames that were substituted for whole sheep when calculating lamb:ewe ratios using this method.

Necks/frame also treated each frame as an independent sample. Each adult and yearling ewe having a clearly photographed neck was classified as collared or non-collared/frame. The same was done for the adult ram population. Neck frames were used to obtain the proportion of necks collared from which a MS estimate of both the ewe and ram populations could be determined.

Population estimates were calculated using the Lincoln-Peterson MS estimator (Overton 1971). Because sampling was conducted with replacement, we adopted a cumulative sample estimator approach based on the binomial probability distribution as described by Wehausen (1990), in which a large random sample was accumulated over time. Rather than interpolate from published tables of binomial confidence limits, we calculated exact 95% confidence intervals for proportions collared as described by Wenstrup (1988). These were then directly substituted to generate confidence intervals for population estimates; and, differences between population estimates were considered significant if their 95% confidence intervals did not overlap (Overton 1971). No confidence intervals were generated for the frame sampling methods due to the lack of independence of samples. For these methods, statistical inference about differences between estimates was possible only when the frame sampling estimate fell within the confidence intervals of the other estimate, in which case it was clear that no difference could be detected. The number of collared animals in the population varied during some sampling periods, and a mean number of collared animals weighted by sample size was used for those MS population estimates.

The population estimates used for comparisons were from a combination of helicopter and ground direct samplings of the population (Wehausen 1990), referred to as multiple direct sampling (MDS). The death of a collared ewe in 1989 was used to separate the sampling periods for MDS population estimates of ewes for 1988 and 1989. The sampling for the 1988 estimate was extended to 15 July 1989 by excluding from the sample ewes born in 1988. The ewe population increase for 1989 was the result of including that cohort in the sampling. The estimate of the 1989 ram population from MDS was based on samplings made between successive December hunting seasons.

Recommendations for statistical analysis of lamb:ewe ratio data have been based on normal approximations under the assumption of sampling without replacement (Otis and Bowden 1979, Czaplewski et al. 1983). Because both our TLS and MDS data approximated sampling with replacement, we instead treated these ratios as proportions and used an analysis based on binomial probabilities identical to that used for the proportion of ewes collared. This amounts to treating the lamb:ewe ratios as the proportion of ewes with surviving lambs. This is reasonable, as lambs are found essentially entirely within ewe groups in the hot season, and most are probably with their mothers.

RESULTS

Mountain sheep used Kerr and Main Peak guzzlers more than Jackass Spring and the Kelso Peak Guzzler (Fig. 1). Jackass Spring in the Marl Mountains showed no sheep use in 1989, even though this spring is located within an area used by ewes and rams. Only 477 uf were recorded at the North Guzzler during 1989 prior to drying up; 9 mountain sheep were recorded during this limited sampling period. The Kelso Peak Guzzler was only used by adult rams. Consequently, TLS data were derived primarily from the Kerr and Main Peak guzzlers.

Comparison of TLS Analysis Methods

The group sampling and necks/frame methods produced essentially identical estimates of the ewe population for the 1989 TLS data (Table 1). Our hypothesis that the group sampling method would produce an overestimate in the proportion collared that would lead to an underestimate for the population size was not supported. The estimates of the ram population did demonstrate the expected relative bias. The group sampling method produced a ram estimate that was lower than that from the necks/frame method. However, the latter estimate fell within the 95% confidence interval of the former (Table 1), and the 2 estimates were not significantly different. Furthermore, the low group sampling estimate may have been a function of the small number of rams sampled.

The group sampling method produced a lamb:ewe ratio that was slightly higher than that estimated by the sheep/frame method (Table 2). This was consistent with our hypothesis if ewes were being underestimated by the group sampling method. However, the difference between the 2 estimates was not significant.

The major difference between the 2 analysis methods was that the frame sampling methods produced inflated sample sizes from which misleadingly narrow confidence intervals for population estimates would result. The sample unit of individual sheep visita used in the group sampling analysis mitigated much of the problem of non-independence. Therefore, this method provided a more valid measure of confidence intervals. Furthermore, the group sampling method took considerably less analysis time than the frame sampling methods. For these reasons, the group sampling method for time-lapse data analysis is recommended for future studies.

Comparison of TLS with MDS

Substantial overlap in confidence intervals resulted in a failure to detect differences in ewe population estimates from TLS and MDS (Table 1). The 1989 TLS estimate for ewes was lower than the corresponding MDS estimate, which would be expected if time-lapse methods
produced higher estimates of the proportions collared. However, the 1988 TLS produced a higher ewe estimate than MDS. Thus, we see no general bias towards underestimation by time-lapse sampling. However, we must temper this conclusion, because the 1988 TLS data were limited by the failure to sample an important water source.

The 1989 TLS estimate of the ram population was notably lower than that produced by MDS; however, due to the small sample size for the TLS data, these estimates also were not significantly different (Table 1). An even smaller sample size precluded a TLS estimate of the ram population for 1988. The small ram sample produced by TLS may be a function of the limited use of the monitored water sources by adult rams. The 1989 MDS estimate of 205 rams, which excluded yearling males, was larger than the estimated ewe population, which included yearling females. The CDFG mountain sheep relocation efforts between 1983 and 1987 removed 87 females and 40 males from this population (Bleich et al. 1990b), and the skewed sex ratio may have resulted from these removals. As measured in sheep/1,000 uf (Fig. 1), ram use of water sources was considerably less than ewe use. If rams and ewes were using these water sources in a similar fashion, ram use should be proportionately greater than ewe use, because of the larger ram population.

The small difference between summer lamb:ewe ratios produced by TLS and MDS was not significant. A substantial decrease in the lamb:ewe ratio between summer and fall of 1989 was documented by MDS (Wehausen 1990). Similarly, we noted a decrease in the proportion of ewes with lambs by separating the TLS data into early summer and late summer samples. This decrease in the lamb:ewe ratio from TLS was consistent with the decline observed by MDS; however, statistical comparisons between the sampling methods were not possible because of differences in the sampling periods.

**DISCUSSION**

We failed to find differences between TLS and MDS population estimates and lamb:ewe ratios. Barring Type I error, this suggests TLS is a valid sampling method for MS estimation of ewe populations in desert mountain ranges with appropriate water distribution. However, we are aware of populations in which the majority of ewes rarely use the available water sources.

We recorded high numbers of ewes at water sources prior to midsummer rains, suggesting that early summer may be the best period for MS estimates of ewe populations in the Mojave Desert. An adequate

<table>
<thead>
<tr>
<th>Year</th>
<th>Sex</th>
<th>No. sampled</th>
<th>Proportion collared</th>
<th>95% C.L.</th>
<th>n collars*</th>
<th>n</th>
<th>95% C.L.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group sampling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1988</td>
<td>Ewe</td>
<td>195</td>
<td>0.123</td>
<td>0.080–0.177</td>
<td>17.00</td>
<td>138.1</td>
<td>95.8–211.2</td>
</tr>
<tr>
<td>1989</td>
<td>Ewe</td>
<td>510</td>
<td>0.118</td>
<td>0.091–0.149</td>
<td>16.50</td>
<td>140.2</td>
<td>110.7–181.3</td>
</tr>
<tr>
<td>1989</td>
<td>Ram</td>
<td>125</td>
<td>0.120</td>
<td>0.069–0.190</td>
<td>16.88</td>
<td>140.7</td>
<td>88.8–245.7</td>
</tr>
<tr>
<td>Necks/frame</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1989</td>
<td>Ewe</td>
<td>3,781</td>
<td>0.118</td>
<td></td>
<td>16.55</td>
<td>140.3</td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>Ram</td>
<td>819</td>
<td>0.107</td>
<td></td>
<td>16.98</td>
<td>158.0</td>
<td></td>
</tr>
<tr>
<td>Multiple direct sampling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1988</td>
<td>Ewe</td>
<td>414</td>
<td>0.135</td>
<td>0.104–0.171</td>
<td>17.00</td>
<td>125.6</td>
<td>99.4–163.9</td>
</tr>
<tr>
<td>1989</td>
<td>Ewe</td>
<td>274</td>
<td>0.098</td>
<td>0.069–0.136</td>
<td>16.00</td>
<td>162.4</td>
<td>117.7–231.9</td>
</tr>
<tr>
<td>1989</td>
<td>Ram</td>
<td>216</td>
<td>0.079</td>
<td>0.047–0.123</td>
<td>16.10</td>
<td>204.6</td>
<td>130.9–346.2</td>
</tr>
</tbody>
</table>

* Weighted mean.
sample of some desert ewe populations may be possible with as few as 3–4 film changes during the early summer period. For ram population estimates, TLS did not provide an adequate sample size. This small sample size may be a function of the apparently limited use of the water sources by rams.

The close correspondence of lamb : ewe ratios from TLS and MDS suggests TLS also can be useful in monitoring recruitment rates of some populations of desert-dwelling mountain sheep. Lamb : ewe ratios determined by TLS may more accurately reflect recruitment rates if sampling can be conducted in the early fall, after summer lamb mortality. The sampling success during this time period may vary as a function of summer precipitation and fall temperatures, and the difficulty associated with identifying large lambs in fall.

Adequate sample size to estimate population parameters is often a problem with desert-dwelling mountain sheep. For MS estimates derived from a sampling-with-replacement approach, TLS analyzed using the group sampling method appears to produce data that are compatible with those from MDS. Thus, combining TLS data with direct observations to significantly increase sample sizes is a useful approach.

**LITERATURE CITED**


