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DESIGN OF AERIAL SURVEYS FOR DALL SHEEP IN THE ARCTIC NATIONAL WILDLIFE REFUGE, ALASKA

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Abstract: Two problems in estimating abundance of Dall sheep from aerial surveys in the Arctic National Wildlife Refuge were considered:
1) allocating survey effort to attain a specified precision, and
2) estimating the bias in detection visibility of animals. Bootstrap computer simulations (resampling with replacement) were used to appraise variation of estimated sheep density from sample data for different sampling schemes. Dall sheep survey data from prior aerial surveys in the Hulahula drainage and from a 1989 sample aerial survey of the Atigun-Sagavanirktok (Atigun-Sag) drainage were the basis for simulations. The bootstrap simulations indicated that the desired precision of 12.5% for the coefficient of variation of the population estimate could be expected by sampling about 8-10 randomly selected drainages (of sizes comparable to the Hulahula and Atigun-Sag study areas) and surveying approximately 50% of each. Two airplanes were used to independently survey subunits of the Atigun-Sag study area. We estimated the probability that a group of sheep will be detected during a survey by using groups detected during the other survey as test cases. The probability of detection was estimated by logistic regression using size of group as an explanatory variable. Procedures to adjust population estimates for visibility bias are illustrated using data from the Atigun-Sag drainage.

The Arctic National Wildlife Refuge (ANWR) in northeast Alaska was expanded in 1980 from 36,000 km^2 to about 76,900 km^2 (Fig. 1). The central purpose for the refuge is to conserve a variety of arctic fish and wildlife species, including Dall sheep (*Ovis dalli dalli*). About 34,000 km^2 (44%) of the Refuge is Dall sheep range, extending over a mountainous area 360 km (225 mi) long, and up to 177 km (110 mi) wide. Although the ANWR is 1 of Alaska's finest Dall sheep habitats and supports a growing portion of the state sheep harvest (16%), a complete inventory of Refuge sheep populations has not been achieved.

Prior to 1988, the abundance of Dall sheep in the ANWR has been measured using fixed-wing aerial "censuses" to obtain direct counts (Smith

1979, Heimer 1983, Garrett 1987). Sheep on portions of the refuge were counted in July and August when snow cover was minimal and visibility was believed to be most favorable. Because of the extensive sheep range within the Refuge and the brief optimal census period, limited portions of the Refuge could be surveyed in a year under conventional funding levels. In the 1970's, 3 years were required to obtain an initial census of most of the sheep range (14,000 km^2) within the original Refuge (Smith 1979). While these surveys provided valuable information on relative abundance and distribution of sheep, they did not provide a means to monitor population status, or to develop population estimates.

With enlargement of the Refuge in 1980, and subsequent increases in hunting, there is a need to develop alternative methods to estimate the abundance of Dall sheep in the ANWR and monitor changes. We are presenting improved sampling designs for aerial surveys which yield: 1) more efficient data collection and analysis, and 2) estimates of parameters with known bias and precision for Dall sheep abundance in the Refuge.

We assume that a 2-stage cluster sampling plan (Cochran 1977) will be recommended. Sampling effort to achieve a desired precision for sheep density (sheep/km^2) is then a function of: 1) the number of primary units (each approximately the size of the Hulahula or the Atigun-Sag study areas) which are sampled from the ANWR; 2) the number of subunits to be sampled from each primary unit; 3) the variance of sheep density between and within the primary units; and 4) the variance due to estimation of visibility bias. It may be possible to further increase precision by stratification of the primary units. However, only stratification of subunits is considered here.

STUDY AREAS

Historic data were used from 4 Dall sheep aerial surveys conducted during mid-July to early August 1976, 1979, 1982, and 1986 in the Hulahula River drainage (Fig. 2, Smith 1979, Heimer 1983, Garrett 1987). Additional data were analyzed from a June 1989 aerial survey of a subset of the Atigun-Sag River drainage (Fig. 3). Summerfield (1974) and Mauer (1990) described physical conditions of the study areas. We analyzed both data sets to develop recommendations concerning design and analysis of aerial surveys for Dall sheep in the entire ANWR.

METHODS

Fourteen subunits with areas from 93 to 150 km^2 were identified in the Hulahula drainage (Table 1, Fig. 2). Two subunits (9 and 12) were not surveyed every year. Data from the 4 Hulahula surveys were compiled by subunit from original field maps and data forms.

Twenty-two subunits with areas from 18-78 km^2 were identified in the Atigun-Sag drainage (Table 2, Fig. 3). The subunits were classified into high, medium, and low sheep-density strata, based on prior knowledge and observed sheep densities during a preliminary aerial survey with about 0.6 minutes per km^2 by a pilot/observer crew in a fixed-wing Piper Super Cub

Table 1. Numbers of Dall sheep observed during the 1976-1986 aerial surveys of the Hulahula region, Arctic National Wildlife Refuge, Alaska, summarized by subunit.

Subunit ID	Area (km^2)	Number of Sheep Counted 1976	1979	1982	1986	Total
1	113.2	35	38	43	86	202
2	130.0	58	49	22	157	286
3	114.4	8	32	57	32	111
4	118.4	33	60	64	104	212
5	93.5	168	121	258	232	679
6	107.7	390	814	583	382	2074
7	107.4	339	201	254	382	1176
8	147.5	103	112	222	363	800
9	101.2	ND[1]	ND[1]	59	31	ID[2]
10	149.9	47	23	71	223	364
11	126.5	192	6	190	372	760
12	130.8	122	ND	60	86	ID[2]
13	140.7	104	72	186	270	632
14	99.1	121	83	125	71	400

[1] No Data; subunit not measured during the particular year.
[2] Insufficient Data; subunits not summed due to missing data.

PA-18. Following stratification, 2 pilot/observer crews in the fixed-wing aircraft independently surveyed a random sample of subunits within the high and medium density strata. One crew conducted an "intensive" survey using about 2.5 min/km^2, while the second conducted a "regular" survey using about 1 min/km^2. In general, the regular survey was conducted at a higher altitude with less circling. Both surveys for each subunit used in analyses were completed within 5 hours of each other. Additional regular surveys were conducted by 1 crew on a larger stratified random sample of subunits from all 3 strata.

Data collected during each survey included the number of groups of sheep detected, number of sheep/group (excluding lambs), locations of groups on topographic maps, composition (mixed, nursery, or rams), number of large males present, and other explanatory variables believed to influence detectability (e.g., measures of topographic relief). Groups were defined as distinct based on location, and sex and age compositions. Immediately after both surveys were completed the pilot/observer teams reviewed observations to determine: 1) groups of sheep detected by 1 team and missed by the other team, and 2) groups detected by both teams. In many cases, groups originally recorded and marked on maps were pooled to account for movement, aggregation, and segregation between surveys based on deductive judgement of the survey crews.

Table 2. Numbers of Dall sheep observed on intensive and regular surveys in the Atigun-Sag area, Arctic National Wildlife Refuge, Alaska, 1989.

Count Block	Stratum[1]	Total Observed Sheep Intensive	Total Observed Sheep Regular
1	High	379	372
3	High		96
13	High	56	54
21	High	56	46
2	Medium		124
5	Medium	114	63
6	Medium		67
8	Medium	87	86
9	Medium	64	51
16	Medium		29
20[2]	Medium	60	29
7	Low		30
10	Low		12
11	Low		8
14	Low		0
17	Low		17

[1] Four additional low-density stratum areas were not surveyed.

[2] Not included in the estimation of visibility bias due to the large time difference between regular and intensive surveys.

Statistical Methods

Simulation methods for estimation of variation between and within drainages.--We simulated the sampling of a large number of drainages with a variable number of subunits per drainage by repeatedly subsampling with replacement from the data i.e., used the bootstrapping procedure (Efron 1982, McDonald et al. 1990). The number of sheep observed per subunit was simulated without correction for visibility bias (Tables 1, 2) under the assumption that variance of the uncorrected counts is approximately equal to variance of counts corrected for bias.

The coefficient of variation (CV) of the density estimate, equal to the standard error of the density divided by the density, was used as a precision criterion. We selected a CV of 12.5%, which corresponds to bounds on a 95% confidence interval of approximately ±25% precision. Graphing the CV plotted against n (number of subunits/primary unit) for various k (number of primary units), we identified the combinations of k and n to be recommended during an aerial survey of ANWR.

Methods for adjusting visibility bias: logistic regression.--The probability that a given group of sheep will be missed during an aerial survey is defined as the *visibility bias* of the group during the survey. Given estimates of the complement (i.e., probability of detecting a group), sample counts may be adjusted for groups missed (Samuel et al. 1987).

An objective of the Atigun-Sag study was to estimate the visibility bias of groups of sheep during regular aerial surveys. The less intense regular aerial surveys might then be conducted on a large sample of subunits and the counts of groups adjusted for groups missed. Given n_1 groups of size 1, n_2 groups of size 2, n_3 groups of size 3, etc. which are detected during the regular survey in a given area, the adjusted number of sheep is

$$T = (\frac{n_1}{p_1} \times 1) + (\frac{n_2}{p_2} \times 2) + (\frac{n_3}{p_3} \times 3) + (\ldots.) \qquad (1)$$

where p_i is the probability of detecting a group of size i.

We identified sheep groups seen during the intensive aerial survey as a test set of sheep groups known present in a given subunit of the Atigun-Sag area. These groups were then either detected or missed during the regular survey of the subunit. We assumed that groups sighted during the intensive survey were a random sample of groups present in the study region. No adjustment was made for counting errors (i.e. we assumed that counts of sheep in groups were correct). We also assumed that movement of sheep between subunits during the 2 surveys was detected by the observers or had negligible effect on the estimates.

The visibility bias of sheep groups during the regular aerial surveys within each density stratum was then estimated using a logistic regression model which is a function of measurable explanatory variables (e.g., Neter et al. 1989, Samuel et al. 1987). The candidate explanatory variables included number of sheep in a group during the intensive survey, intensity of the survey (minutes/km^2 spent surveying the subunit), subunit stratum (medium or high), group composition (mixed, nursery, or rams), geology type of substrate and five measures of topographic relief (McDonald et al. 1990). The fit of a model was evaluated by the likelihood ratio test and goodness-of-fit statistics (SAS 1988). Results of the logistic regressions for the medium density stratum were assumed to apply to counts in the low density stratum because no intensive surveys were conducted in the low density stratum.

Methods for adjusting visibility bias: double sampling.--A second technique for adjusting for visibility bias is *double sampling* (Eberhardt and Simmons 1987, Gasaway et al. 1986) in which the quick and less expensive "regular" aerial survey is calibrated by the more accurate, but more expensive "intensive" aerial survey. A ratio of counts from these 2 surveys is constructed from a "small" sample where both are conducted. The ratio is then used to adjust the total number of sheep estimated from a "large" sample where the regular survey is conducted.

Double sampling was used to adjust the estimated sheep abundance from regular surveys in the Atigun-Sag region of the ANWR, June 1989, under the assumptions that no groups are missed during intensive surveys and counting errors are negligible. For subunits where both surveys were conducted, the ratio of the number of sheep seen during the intensive survey (y_i) to the number of sheep seen during the regular survey (x_i), totalled over all sheep groups is

$$R = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} x_i} \quad (2)$$

This ratio provides a calibration term with which to adjust the count of sheep detected during regular surveys to the estimated number that would have been detected if the intensive survey were conducted on all sampled subunits. The double sampling procedure was evaluated within each stratum of the Atigun-Sag study area and for the entire study area ignoring stratum boundaries.

RESULTS

Simulations Based on the Hulahula Drainage

Using the bootstrap procedure for resampling subunits from Table 1, the coefficient of variation of the estimated density of sheep was simulated. We considered various combinations of the number of primary units (drainages) to be randomly sampled with the requirement that an equal number of subunits (count blocks) be subsampled from each primary unit. Results of 2 of these simulations (1979, 1982) are plotted in Figs. 4-5, respectively. Based on Fig. 5, we expect that the desired coefficient of variation of 12.5% can be achieved by random sampling about 8 primary units and subsampling about 8-10 subunits from each primary unit. All simulations conducted on the surveys of the Hulahula drainage yielded approximately the same results with the exception of those for 1979 data (Fig. 4). Based on the variation observed in 1979, a larger sampling effort of about 15 primary units and 10 subunits per primary unit would be required to meet the stated goal for precision.

Simulations Based on the Atigun-Sag Drainage

For simple random sampling of the data (Table 2), we expect that the desired precision of CV = 12.5% will be achieved with about 15 primary units and about 6 subunits each (Fig. 6). However, the same sampling effort in stratified random sampling (8-10 primary units with 3 subunits from each of 3 strata) is expected to yield estimates with approximately 12.5% CV (Fig. 7).

Estimation of Dall Sheep Abundance for the Atigun-Sag Drainages

The numbers of sheep counted during regular surveys (uncorrected for visibility bias) ranged from 48-99% of the numbers counted during intensive surveys on units where both were conducted. Correlation analyses revealed that counts from the 2 surveys had correlation coefficients of $r = 0.99$ ($P < 0.02$) for subunits in the high density stratum and $r = 0.54$ ($P = 0.64$) for subunits in the medium density stratum.

The number of sheep in a group was the lone significant explanatory variable in the logistic regressions ($P = 0.02$, medium density stratum; $P = 0.03$, high density stratum). In each stratum, the model selected for estimating the probability of detecting a given group of sheep during the regular surveys was

$$p = \frac{e^{(my)}}{1+e^{(my)}} \qquad (3)$$

where m is the regression coefficient, and y is the number of sheep in the group. For example, the probability of detecting a group of size y during the regular surveys in the medium density stratum is given in equation (4) and is plotted in Fig. 8.

$$p = \frac{e^{(0.1504)y}}{1 + e^{(0.1504)y}} \qquad (4)$$

The number of groups of size y detected during a regular survey, n_y, was adjusted to n_y / p_y to account for groups of size y which were missed by the regular survey. This adjustment for visibility bias is tedious and no formula is available for estimating the standard error of the estimated total sheep. Because of this problem a jackknife procedure was used within each stratum to estimate the standard error (Krebs 1989, McDonald et al. 1990). The jackknifed pseudovalues within a stratum were computed by: 1) dropping 1 subunit at-a-time from a stratum; 2) fitting the logistic regression model (3) to the remaining data; 3) adjusting the counts of sheep in groups detected during regular survey flights of other subunits in the stratum; and 4) expanding the adjusted counts to the entire stratum. The mean and standard error of the pseudovalues were then computed.

Estimates of total sheep for the high, medium and low density strata were 762 (SE = 234.7), 632 (SE = 28.2), and 198 (SE = 23.5) sheep, respectively. Summing across the 3 strata, the estimate of total sheep in the Atigun-Sag study area, June 1989, was 1592 (SE = 237.6).

Using the double sampling approach, the ratio of sheep sighted in the intensive surveys to the sheep sighted in the regular surveys was 1.325 in the medium density stratum and 1.04 in the high density stratum. We used the ratio 1.325 to make adjustments in the low density stratum. Applying these ratios to the regular surveys, we obtained estimates of 591 (SE = 8.0), 595 (SE = 85.0), and 178 (SE = 53.2) for the high, medium, and low density strata, respectively. Summing across the 3 strata, the estimate of total sheep in the Atigun-Sag study area, June 1989, was 1364 (SE = 100.8).

DISCUSSION AND RECOMMENDATIONS

Adjustments for Visibility Bias

Groups of sheep detected during the intensive surveys were used as test cases for estimating probability of detection during regular surveys. The major problem was that some groups were pooled while the pilot/observer crews were judging which groups detected during an intensive survey were also detected (or missed) during a regular survey. We believe there was a tendency for the pilot/observer of the regular survey to judge that they had also seen these pooled groups when in fact they may have been detecting groups missed during the intensive survey. Also, there was a tendency of the regular survey crew to judge that small groups had moved and were detected in both surveys. The effect of these biases is to overestimate the probability of detection of groups of sheep during the regular survey and underestimate the total abundance of sheep. We therefore believe that the estimate of 1592 Dall sheep (s.e. = 238) for the Atigun-Sag study region, June 1989, is conservative.

While the population estimate (1364 sheep) based on double sampling is still lower, confidence intervals for the 2 estimates overlap. However, we are more confident in the first approach because we believe that 1592 sheep is an underestimate, and it is larger than the corresponding estimate from the double sampling approach. In effect, we believe that a number of Dall sheep were missed during the intensive survey.

Factors Influencing the Probability of Detection

Among several variables tested, only group size was significantly related to probability of detection. Other tested variables may not have been significant because of measurement error or our inability to measure ecological and physical reality. In particular, we expected topographic relief to be related.

Sampling Strategy

Simulations of stratified random sampling of subunits from the Atigun-Sag study region resulted in smaller coefficients of variation of estimated sheep density relative to simple random sampling of subunits from either the Hulahula or the Atigun-Sag study regions. Thus, we were able to attain the desired precision with a smaller sampling effort because densities of sheep were more homogeneous over subunits within strata. We attribute the ability to define strata with more homogeneous distributions to seasonality; the Atigun-Sag region was surveyed in June while the Hulahula region was surveyed in July-August. Regions of "high", "medium", and "low" densities were relatively easy to delineate during the June 1989 study. We recommend that surveys be conducted in early summer using a stratified random sampling procedure within major drainages.

Simulations from the Hulahula survey indicate that precision of CV = 12.5% for sheep density in ANWR can be expected in many years by random sampling of 8-10 subunits in about 8 randomly selected primary units. Simulations of the 1989 Atigun-Sag data indicate that about 9 primary units would be needed with 8-10 subunits each to achieve a CV of 12.5% for both simple random and stratified random sampling of subunits.

Two factors tend to increase the recommended sample sizes: 1) there was higher variation in the 1979 aerial survey of the Hulahula drainage and the desired precision could only be obtained for the highest sampling effort simulated, and 2) the simulations did not include the variation due to adjusting for visibility bias. On the other hand, 2 factors tend to decrease the recommended sample sizes: 1) 27 primary units have been tentatively identified in ANWR and a sample of 8-10 primary units will yield a finite population correction factor which will reduce the CV by about 15% (e.g., (0.85)12.5% CV = 10.6% CV), and 2) stratification of primary units may further reduce variation.

It is impossible to precisely predict the required sampling effort in a future aerial survey of ANWR because data are available from only two drainages and a small number of years. Never-the-less, for a refuge-wide survey of ANWR we recommend that: 1) the refuge be divided into major drainages (primary units) of sizes comparable to the Hulahula and Atigun-Sag study areas; 2) the primary units be stratified into "high", "medium", and "low" sheep density areas based on judgement and prior knowledge; 3) 8-10 primary units be randomly selected in a stratified random design (e.g., 4 units from the high density stratum, 3 from medium density stratum, and 2 from the low density stratum); 4) divide each selected primary unit into subunits which can be surveyed in relatively short periods ($\leq$1.5 hours) when flying at about 1 minute/km^2; 5) pre-stratify all subunits in a given primary unit based on prior knowledge and a preliminary "stratification" survey (e.g., flying at about 0.6 minute/km^2) immediately before the formal survey(s); 6) randomly select 2-4 subunits from each stratum identified for formal survey(s) (e.g., 4 subunits from the high density subunits, 3 from medium density subunits, and 2 from the low density subunits); 7) conduct "regular" surveys in each subunit identified in 6); 8) also, conduct "intensive" surveys on approximately one-third of the subunits identified in 6); and 9) develop models for correction of visibility bias in regular surveys using logistic regression of groups detected (or missed) in the intensive survey on explanatory variables. There are no guarantees associated with recommendations of this nature. We anticipate that refuge-wide estimates will be obtained with CV $\leq$12.5 % based on this design and sampling effort.

LITERATURE CITED

Cochran, W. G. 1963. Sampling Techniques, 2nd Ed. John Wiley and Sons, Inc., New York, NY. 413pp.

Eberhardt, L. L. and M. A. Simmons. 1987. Calibrating population indices by double sampling. J. Wildl. Manage. 51:665-675.

Efron, B. 1982. The jackknife, the bootstrap and other resampling plans. Society for industrial and applied mathematics, Philadelphia, Pennsylvania. 92pp.

Garrett, D. P. 1987. Population size, composition, and distribution of Dall sheep in the Hulahula river and adjacent drainages, Fall 1986. Tech. Rpt. Arctic National Wildlife Refuge, U. S. Fish and Wildl. Service, 101 12th Avenue, Box 20, Fairbanks, AK 99701.

Gasaway, W. C., S. D. DuBois, D. J. Reed and S. J. Harbo. 1986. Estimating moose population parameters from aerial surveys. Biological papers, University of Alaska, No. 22. 108 pp.

Heimer, W. E. 1983. Dall sheep survey: Hulahula River--July 1983. Memorandum, Alaska Div. of Game, Dept. of Fish and Game, 1300 College Drive, Fairbanks, AK 99701.

Krebs, C. J. 1989. Ecological Methodology. Harper and Row, New York, NY. 654 pp.

Mauer, F. J. 1990. Dall sheep investigations in the Arctic National Wildlife Refuge, Progr. Rpt., Arctic National Wildlife Refuge, USFWS, 101 12th Avenue, Box 20, Fairbanks, AK 99701.

McDonald, L. L., H. B. Harvey, F. Mauer and A. Brackney. 1990. Design of procedures for estimation of the size and composition of Dall sheep populations in the Arctic National Wildlife Refuge. Tech. Rpt. Depts. of Statistics and Zoology, University of Wyoming, Laramie, WY 82071.

Neter, J., W. Wasserman and M. H. Kutner. 1989. Applied linear regression models, 2nd Ed. Irwin, Boston. 667pp.

Samuel, M. D., E. O. Garton, M. W. Schlegel and R. G. Carson. 1987. Visibility bias during aerial surveys of elk in northcentral Idaho. J. Wildl. Manage. 51:622-630.

SAS Institute. 1988. SAS/Stat VMS SAS Release 5.18. SAS Institute, Inc., Cary, North Carolina.

Smith, T. 1979. Distribution and abundance of Dall sheep in the Arctic National Wildlife Range. Tech. Rpt. Arctic National Wildlife Refuge, U. S. Fish and Wildlife Service, 101 12th Avenue, Box 20, Fairbanks, AK 99701.

Summerfield, B. L. 1974. Population dynamics and seasonal movement patterns of Dall sheep in the Atigun canyon area, Brooks Range, Alaska. M. S. Thesis, Univ. of Alaska, Fairbanks, AK 99705. 109 pp.

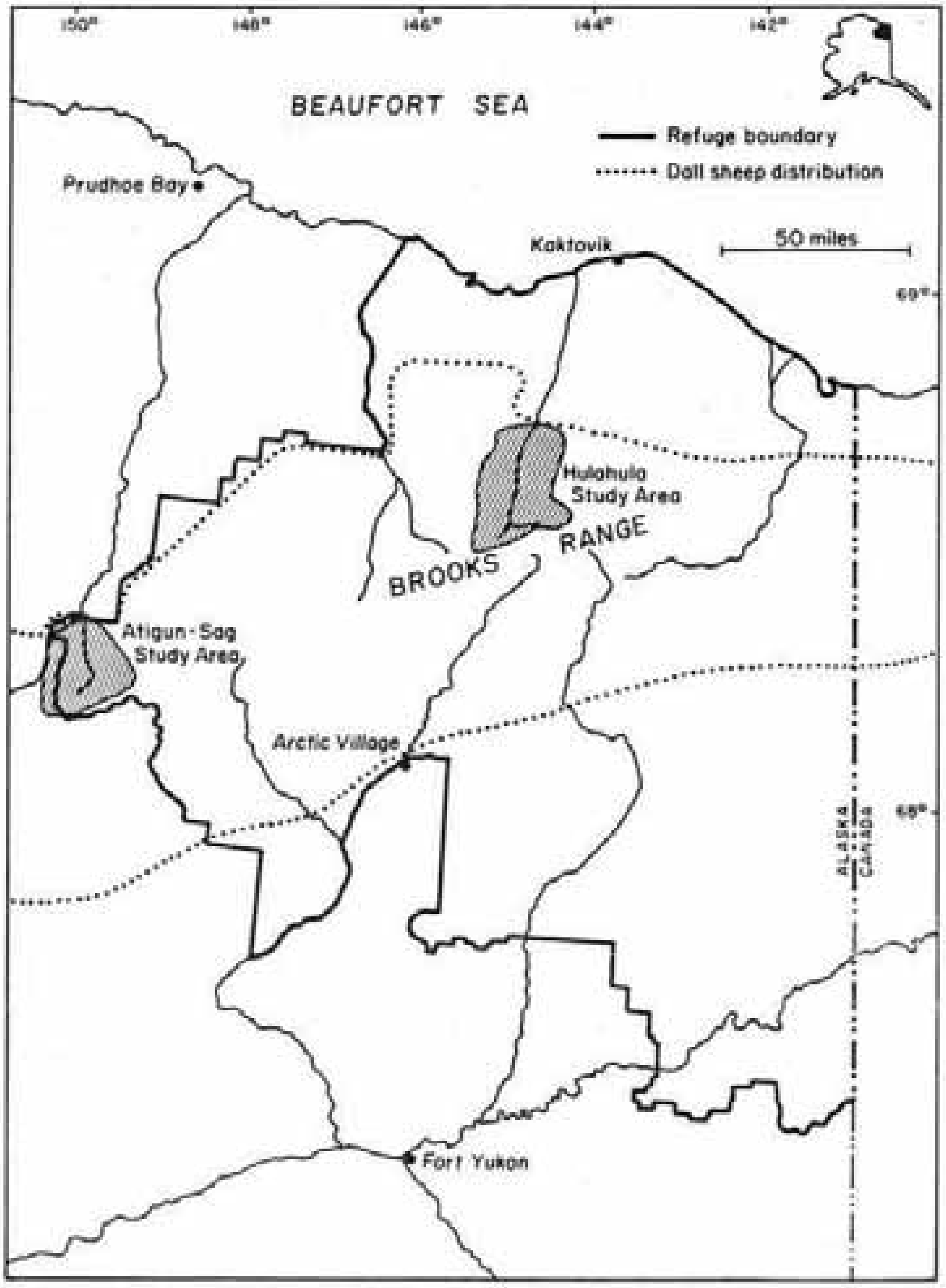

Fig. 1. Locations of 2 study areas within the Arctic National Wildlife Refuge.

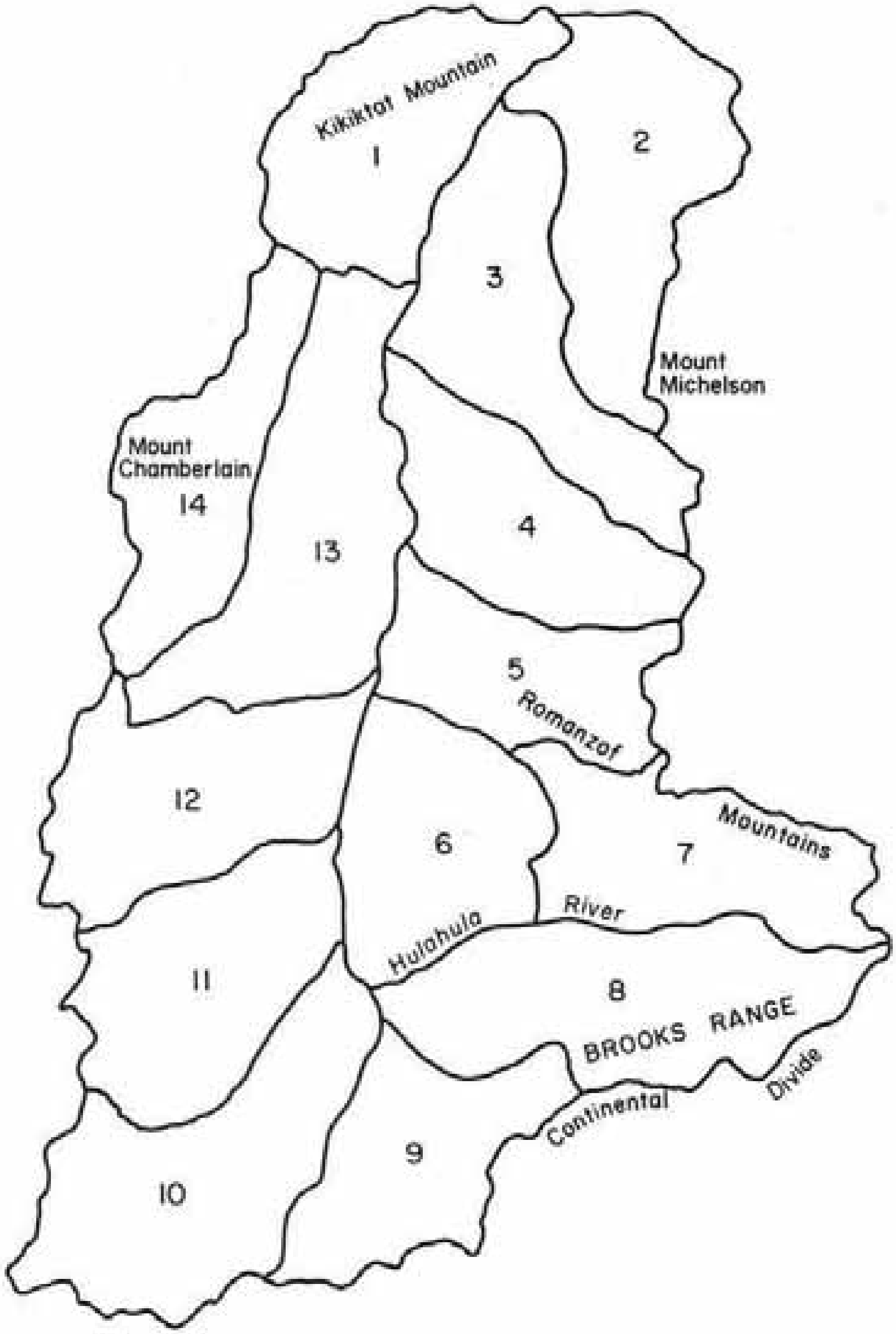

Fig. 2. Hulahula study area with Dall sheep survey subunits outlined.

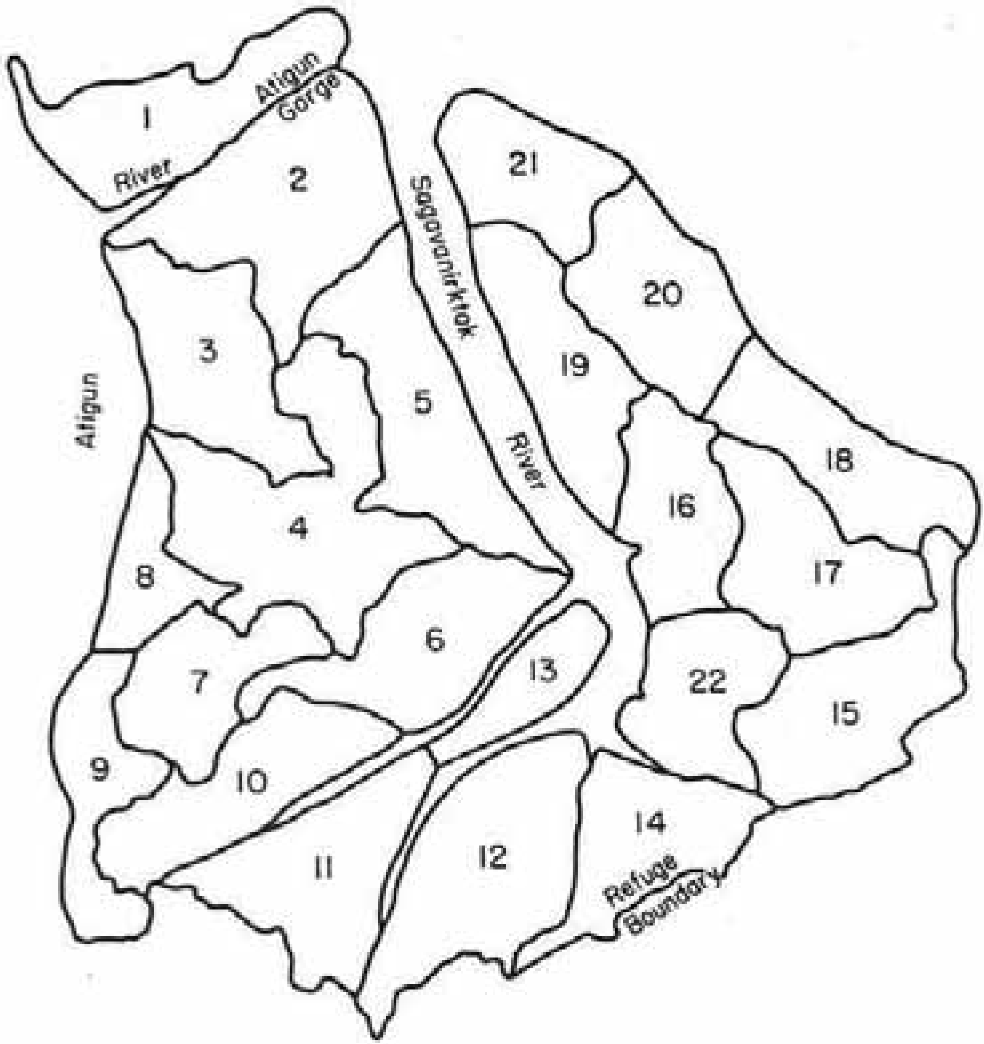

Fig. 3. Atigun-Sag study area with Dall sheep survey subunits outlined.

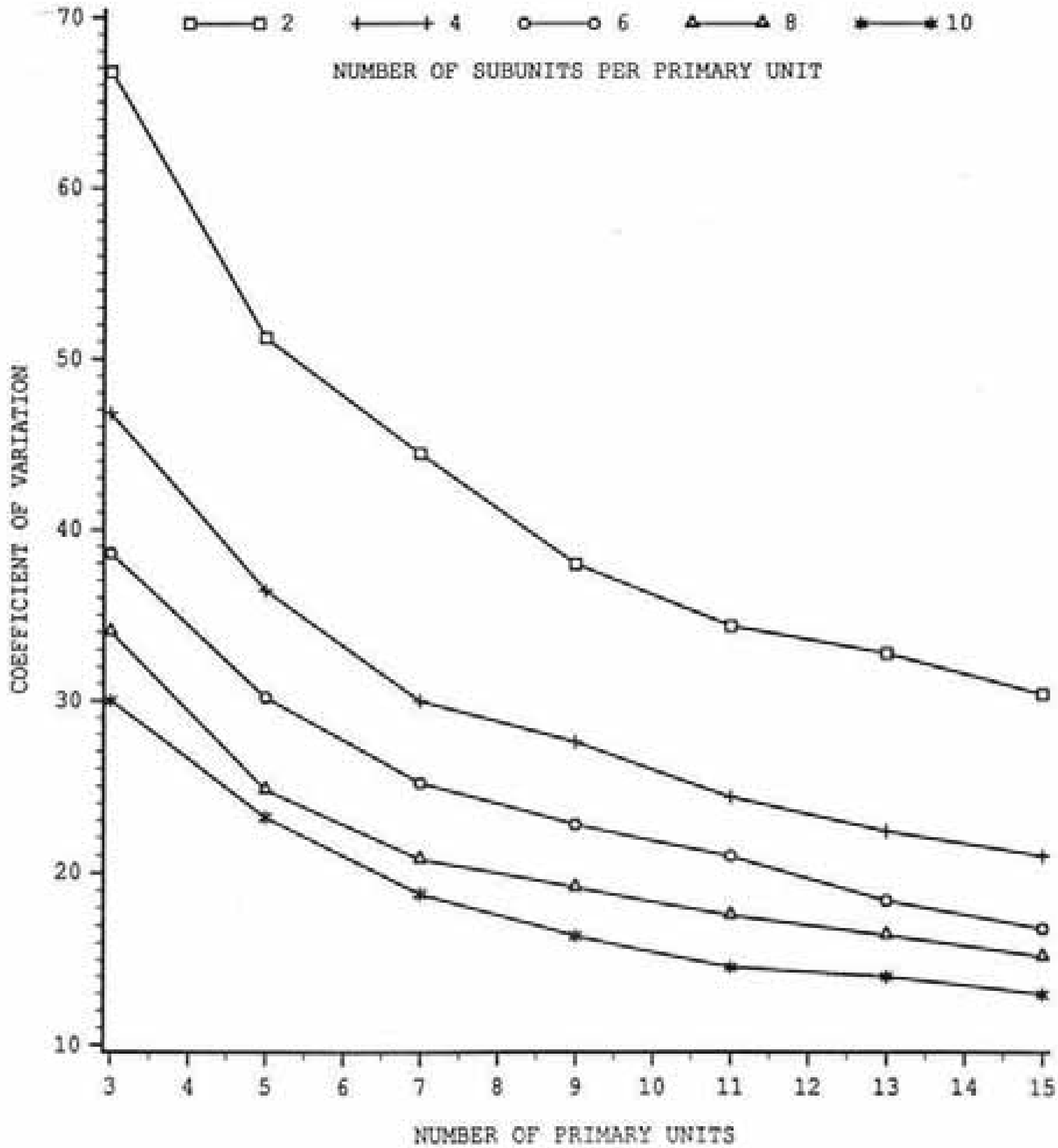

Fig. 4. Simulated coefficients of variation (CV) of estimated Dall sheep density based on simple random sampling of subunits from the Hulahula study area, 1979. CV's are plotted as a function of the number of primary units selected and the number of subunits surveyed per primary unit.

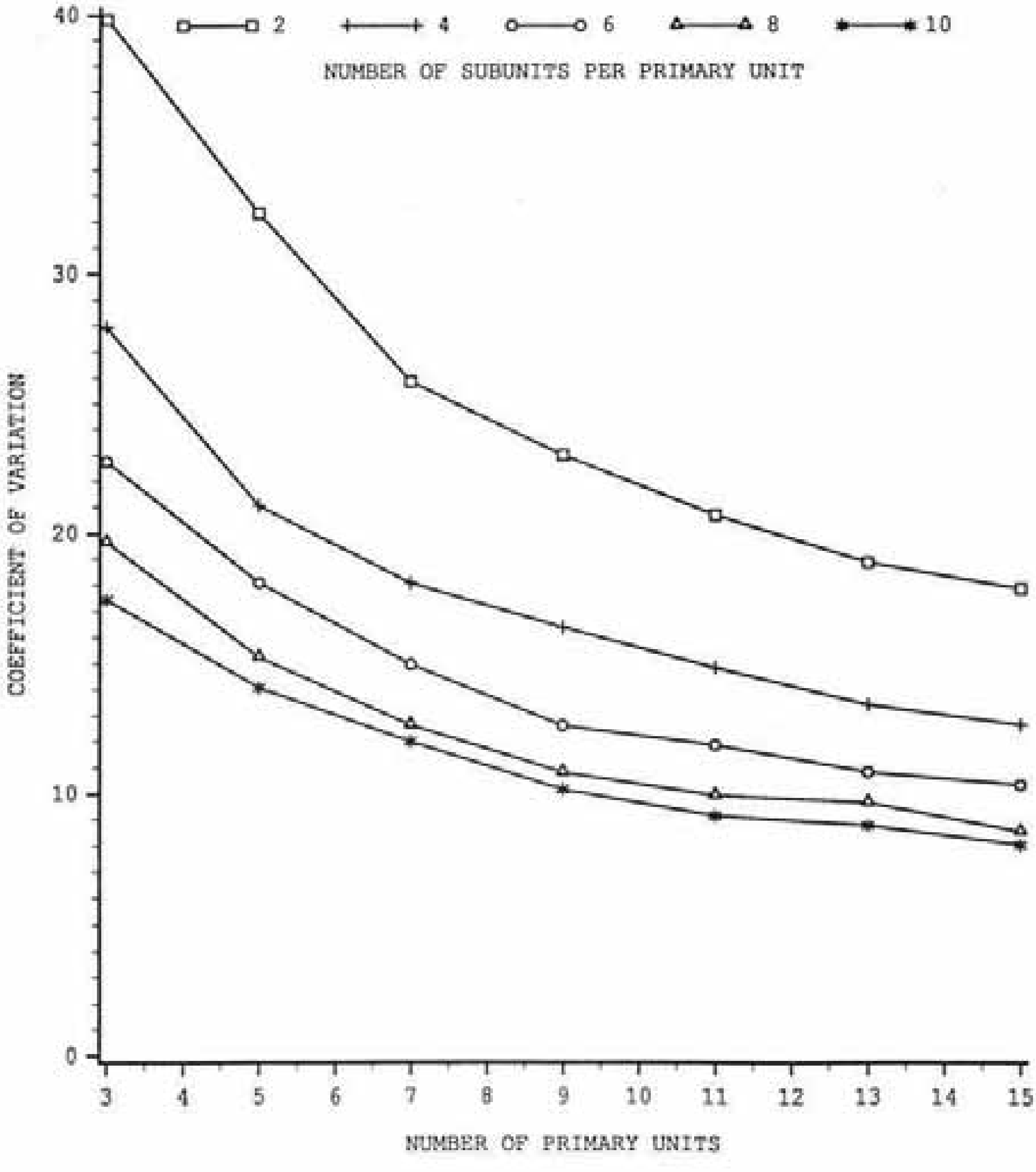

Fig. 5. Simulated coefficients of variation (CV) of estimated Dall sheep density based on simple random sampling of subunits from the Hulahula study area, 1982. CV's are plotted as a function of the number of primary units selected and the number of subunits surveyed per primary unit.

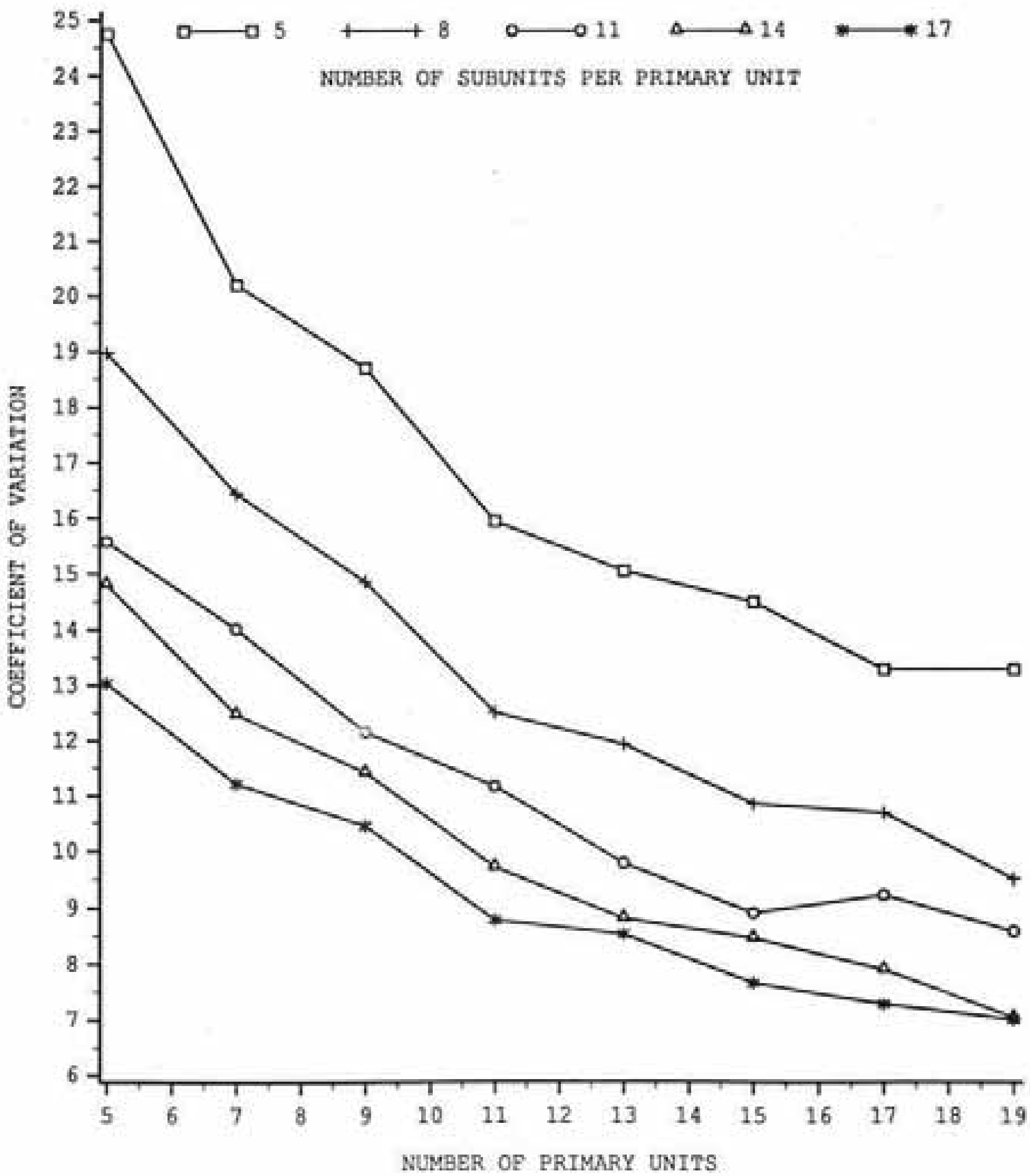

Fig. 6. Simulated coefficients of variation (CV) of estimated Dall sheep density based on simple random sampling of subunits from the Atigun-Sag study area and regular survey data, 1989. CV's are plotted as a function of the number of primary units selected and the number of subunits surveyed per primary unit.

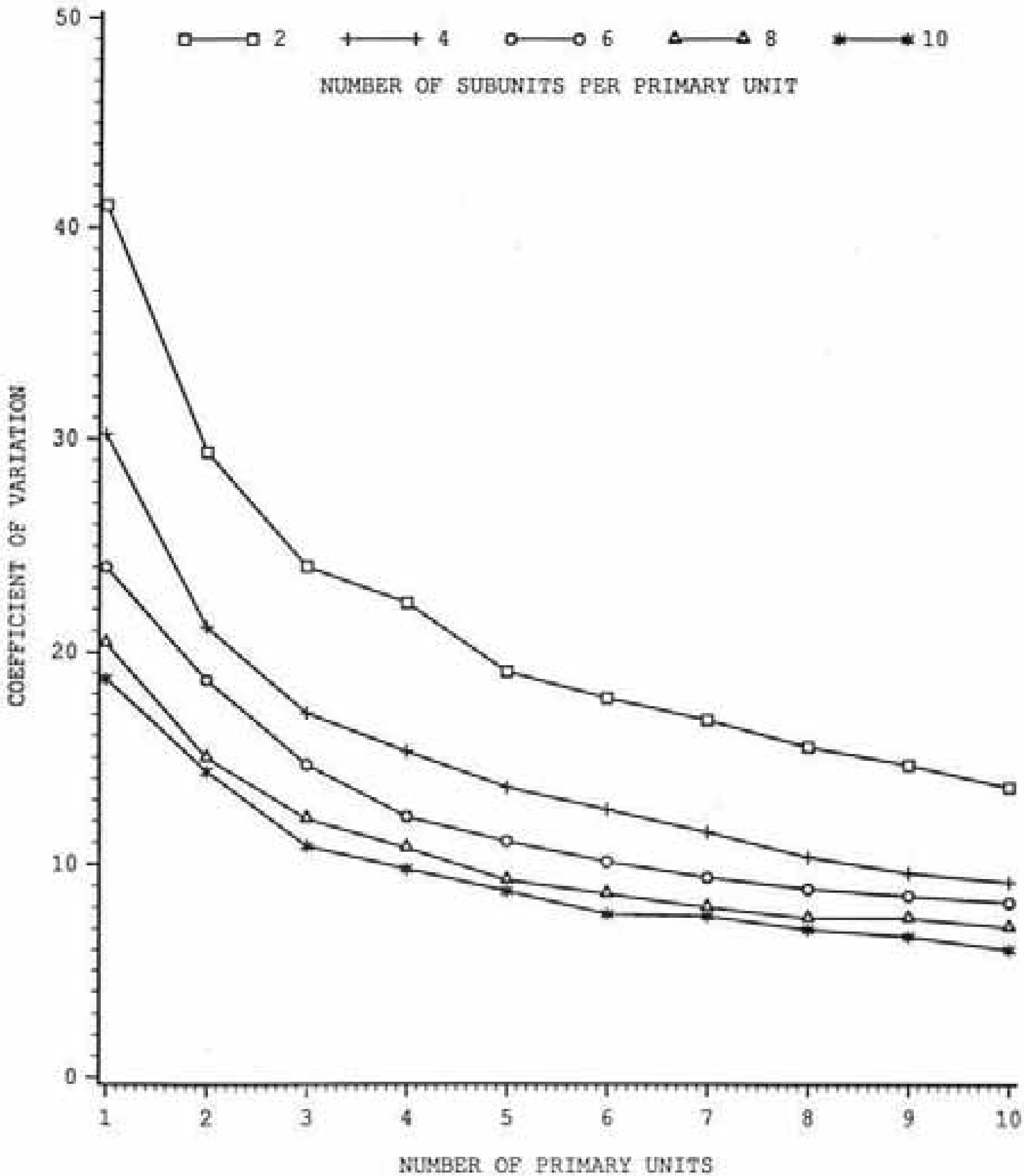

Fig. 7. Simulated coefficients of variation (CV) of estimated Dall sheep density based on stratified random sampling of subunits from the Atigun-Sag study area and regular survey data, 1989. CV's are plotted as a function of the number of primary units selected and the number of subunits surveyed per stratum.

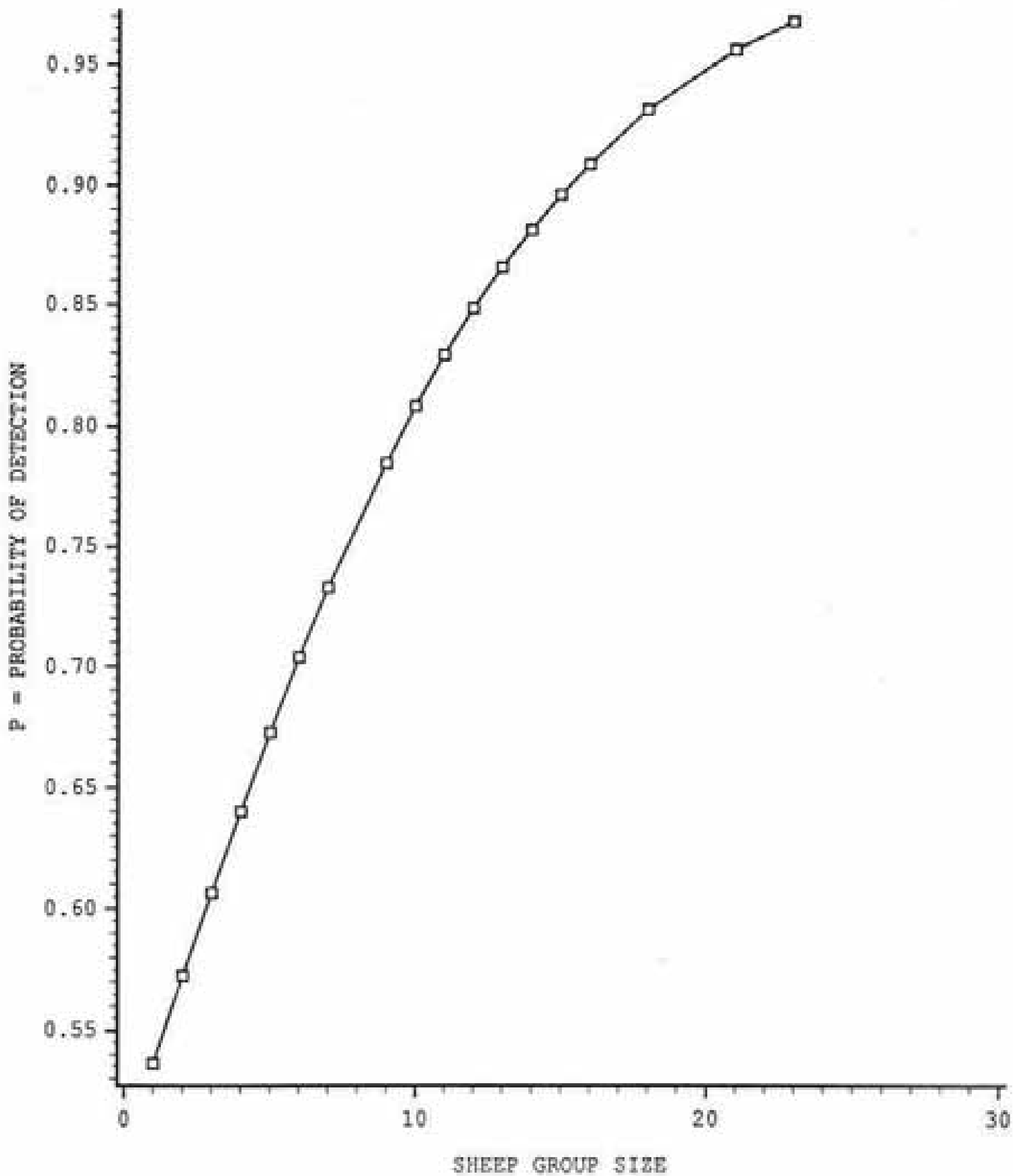

Fig. 8. Estimated probability of detection (Equation (4)) of a group of Dall sheep as a function of number of sheep in the group during the regular surveys of units in the medium density subunits, Hulahula and Atigun-Sag study areas, Alaska.