Alaska Department of Fish and Game
Division of Wildlife Conservation
June 1997

Estimating Population Size and Composition of Dall Sheep in Alaska: Assessment of Previously Used Methods and Experimental Implementation of New Techniques

Kenneth R. Whitten

Federal Aid in Wildlife Restoration
Research Final Report
1 July 1994–31 December 1996

Grants W-24-3, W-24-4, W-24-5
Study 6.11

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Mary Hicks
Publications Specialist
ADF&G, Wildlife Conservation
P.O. Box 25526
Juneau, AK 99802
(907) 465-4190

RESEARCH FINAL REPORT

STATE: Alaska **STUDY NO.:** 6.11

COOPERATORS: None

GRANT NO.: W-24-3, W-24-4, and W-24-5

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AUTHOR: Kenneth R Whitten

PERIOD: 1 July 1994-31 December 1996

SUMMARY

We developed a new technique for estimating abundance of Dall sheep (*Ovis dalli*) by aerial survey. We divided large areas of sheep habitat into sampling units of 30 to 90 km^2 each and searched all or most units at relatively low intensity (0.74-0.93 min/km^2) by fixed-wing Supercub aircraft. We then resurveyed a subsample of units at higher intensity (0.97-1.34 min/km^2) with a Robinson R-22 helicopter. We used the generally higher helicopter counts to calculate sightability correction factors for fixed-wing surveys and estimate the number of sheep we would have seen if we had surveyed entirely by helicopter. We estimated 1942 sheep ± 17% (90% CI) in Unit 20A in 1994, 1673 ± 14% in the Delta Controlled Use Area in 1995, and 2758 ± 8% in a portion of Gates of the Arctic National Park and Preserve in 1996. We attempted to maintain consistent search intensities within and among surveys, but search efforts expressed in terms of minutes of flight time per km^2 varied with terrain complexity. In Gates of the Arctic we failed to maintain sufficiently high search intensity in helicopter counts relative to fixed-wing counts and consequently underestimated sheep relative to the other study areas. Nevertheless, our helicopter search effort was still as high or higher than in previous surveys of Gates of the Arctic, and our current estimate is a conservative basis for management decisions. Sheep in all study areas have declined from estimates made approximately 10 years ago, most likely in response to severe winters between 1988 and 1993. High lamb and yearling counts in all areas indicate that sheep are now recovering. Calculated sex and age composition ratios had wide confidence intervals, probably reflecting natural variation in geographic distribution of various social groupings of sheep. Although more costly than fixed-wing aircraft, the R-22 helicopter was a superior survey vehicle. Our combination fixed-wing/helicopter approach shows great promise for larger areas where surveying by helicopter alone would be cost-prohibitive.

Key words: aerial survey, composition, Dall sheep, *Ovis dalli*, population estimation.

CONTENTS

BACKGROUND

For many years Alaska Department of Fish and Game (ADF&G) Dall sheep (*Ovis dalli*) research depended on observations of seasonal concentrations of sheep at mineral licks (Heimer and Watson 1986). Analysis of observations from licks must account for differential visitation rates for various sex/age classes of sheep and for multiple visits by the same individuals. Adjustments depend on availability of marked or collared sheep. Intensive marking and monitoring is also necessary to determine if sheep use 1 lick or multiple licks, whether those licks are within the study area, and whether some sheep in the study area may not use licks at all. Some sheep fail to visit licks each year (Heimer 1987), and rams do not use licks as reliably as females and young. Finally, observations from licks may not be applicable to populations in other areas with different predator populations or harvest pressures. Therefore, ADF&G sheep research in recent years has relied increasingly less on observations of sheep at licks.

During summer, all-white Dall sheep on their alpine tundra ranges are highly visible against both vegetated and unvegetated backgrounds. Sheep are generally too scattered for aerial photo counts, and rugged mountains and canyons in most sheep habitat make aerial transect surveys unfeasible. Nevertheless, large areas of sheep habitat can be covered relatively quickly by air, and intensive fixed-wing or helicopter surveys have become the most common method for routine monitoring of Dall sheep populations in Alaska.

Use of fixed-wing aerial surveys for detailed monitoring of sheep population dynamics is compromised, however, by difficulties in classifying various sex/age classes from the air. Multiple low-level passes to obtain composition data in rugged mountain terrain can be dangerous to biologists and pilots, as well as disruptive to sheep. Under the best conditions, large rams and young lambs are clearly distinguishable and adult rams can be further divided into subgroups according to horn size, but young rams (< 1/2-curl), yearlings, and ewes tend to look alike from an airplane. This forces biologists to compare numbers of lambs or rams to numbers of "ewelike" sheep, and the composition of ewelike animals varies irregularly in relation to yearling recruitment. More accurate composition classifications by ground-based observers are sometimes used to adjust aerial survey data (Whitten 1975, Heimer and Watson 1986), but ground-based surveys can usually cover only small areas and may not be applicable to larger areas surveyed by aircraft.

Classification difficulties in aerial surveys can be greatly reduced by using helicopters instead of fixed-wing aircraft. Observers in helicopter surveys of Denali and Gates of the Arctic National Parks found far more sheep than had been counted in previous fixed-wing surveys and concluded that sightability in helicopter surveys must be higher (Singer et al. 1981, Singer 1984). Researchers in Wrangell-St Elias National Park compared helicopter and fixed-wing counts of the same areas and also concluded helicopters were superior search vehicles (Strickland et al. 1992*b*). In contrast, Heimer and Watson (1982) claimed that helicopters are less cost-efficient than fixed-wing aircraft for counting sheep and that helicopter noise causes sheep to flee and/or hide, actually resulting in lower sightability rates than in fixed-wing surveys.

Biologists seem to feel confident about trends indicated by their various sheep survey techniques, in spite of lingering disagreement over which techniques work best (Singer 1984, Heimer and Watson 1986, Harkness 1990). However, accuracy and precision of past sheep population estimates are unknown, and most long-term data sets show fluctuations in numbers and/or composition which are inconsistent with reasonable mortality and recruitment. These aberrations cast doubt on our ability to detect short-term population changes using existing survey techniques. Detecting even long-term fluctuations may be difficult in areas where surveys are infrequent.

Estimation of moose and caribou populations was in a similar state of confusion until the late 1970s, when application of new and statistically sophisticated techniques improved understanding and management (Davis et al. 1979, Gasaway et al. 1986). The purpose of this study was to develop a statistically sound survey method that would similarly improve our understanding and management of sheep.

We chose 3 study areas where sheep had recently declined coincident with a series of severe winters in the late 1980s and early 1990s. In 1994 we surveyed Unit 20A in the Alaska Range south of Fairbanks. Unit 20A has long been managed to maximize opportunities to participate in sheep hunting. Sheep harvests averaged 150 full-curl rams in the mid-1980s but declined to about 50 rams by 1993. In 1995 we surveyed the Delta Controlled Use Area (DCUA), just east of Unit 20A. The DCUA is managed under a drawing permit system to provide for aesthetically pleasing hunting through restriction of hunter numbers, access, and means of transportation. In 1996 we surveyed portions of Gates of the Arctic National Park and Preserve in the Brooks Range. Our count covered an area of the preserve open to all hunters as well as park lands near Anaktuvuk Pass used exclusively by federally qualified subsistence hunters.

Our new survey technique used low-intensity fixed-wing surveys to quickly and inexpensively search all sheep habitat. We then flew higher intensity searches of some sample units by helicopter to develop a sightability correction factor (SCF) for adjusting the low-intensity counts. Our final estimate was comparable to what we would have counted in a high-intensity helicopter search of the entire area, except that our estimate gave statistical confidence intervals. We classified sheep only as lambs or adults in fixed-wing counts but made more detailed composition classifications from the helicopter.

OBJECTIVES

- Review ADF&G and other agency reports on Dall sheep survey techniques.
- Review appropriate literature on other wild sheep, mountain goat, and alpine ungulate survey techniques.
- Review results of previous ADF&G surveys for possible application of statistical analyses to determine confidence intervals or sightability correction factors.
- Develop new or modified techniques for testing during future sheep surveys.

STUDY AREAS

Unit 20A contains about 3000 km^2 of sheep habitat in the Alaska Range south of Fairbanks, Alaska. The DCUA covers approximately 1500 km^2 of sheep habitat immediately east of the Unit 20A study area and includes portions of Units 20D, 13B, and a small part of Unit 20A not covered in the previous year survey. The study area in Gates of the Arctic National Park and Preserve covered portions of Units 24, 26A, and 26B and included about 5750 km^2 of sheep habitat extending along the continental divide from Atigun Pass in the east to the Okokmilaga River in the west.

METHODS

We divided Dall sheep habitat in each study area into sample units of 30 to 90 km^2 each. There were 51 sample units in Unit 20A, 27 in the DCUA, and 89 in Gates of the Arctic. Because sheep are usually at high elevations during midsummer, we avoided ridgetops and used drainage bottoms as unit boundaries to reduce chances of finding sheep on or crossing boundaries during surveys. In Unit 20A and the DCUA, we surveyed every sample unit at relatively low intensity with fixed-wing aircraft (Piper PA-18 Supercubs with pilot and 1 observer). In Gates of the Arctic, we surveyed 78 of 89 units by fixed-wing. Observers searched for sheep by following contour lines and flying as many contours as necessary to get a good look at all terrain. Actual flight times per km^2 varied with complexity of terrain for different sample units, but we considered overall search intensity uniform. Observers circled over groups of sheep only as necessary to obtain accurate counts and classified sheep only as adults or lambs. Locations of sheep were marked on 1:63,250 series USGS maps.

We randomly selected a third of the sample units in Unit 20A and the DCUA to search at higher intensity, using a Robinson R-22 helicopter with pilot and 1 observer. In Gates of the Arctic we allocated survey effort between fixed-wing and helicopter searches using a model that took into account relative aircraft operating costs and variance parameters data from the previous 2 surveys. We recalculated allocation several times as the survey progressed and ultimately resampled 34 (50%) of the fixed-wing sample units by helicopter. In addition, bad weather and logistic constraints caused us to sample 11 units by helicopter only in the Gates of the Arctic survey. During high-intensity searches observers circled back over rough or broken terrain and spent as much time in each sample unit as they felt necessary to thoroughly search for all sheep; they counted and mapped sheep as in the low-intensity counts. In Unit 20A observers attempted to classify sheep as lambs, ewes, < 1/4-curl rams, 1/4-7/8-curl rams, or full-curl rams. In the DCUA and Gates of the Arctic, high-intensity count observers classified sheep as ewes, lambs, yearlings, and Class I, II, III, or IV rams (after Geist 1971). We began high-intensity counts as soon as possible (usually < 30 min) after the low-intensity search of the same sample unit although in a few cases we did the high-intensity count first.

We entered data from low- and high-intensity surveys into the computer program MOOSEPOP to estimate a SCF for low-intensity counts (Gasaway et al. 1986). MOOSEPOP used the SCF to estimate the sheep population for the entire area covered by low-intensity survey. In the Gates of the Arctic count, we added unadjusted sheep numbers from units counted by helicopter only to obtain the overall study area estimate. Sightability correction for the high-intensity surveys could not be calculated, so we could not estimate true population sizes. Our population estimates were the numbers of sheep we should have seen in each study area had it been covered entirely by high-intensity helicopter survey. We also used MOOSEPOP to estimate composition of the sheep population, based only on high-intensity survey data.

Detailed maps of all study areas and sample units are archived at ADF&G in Fairbanks, Alaska. Maps include marked locations of sheep sightings coded to field data sheets showing number and composition of sheep. Field data for Gates of the Arctic are also archived at the National Park Service in Fairbanks.

RESULTS

Due to inclement weather, we were unable to survey the westernmost sample unit, along McGinnis Creek, in the DCUA. Very few sheep have been found in this area in recent years, and none was seen in the adjacent sample unit during our survey. Thus, our estimates of sheep in the DCUA should have been little affected by missing this unit. Similarly, we did not count 2 sample units immediately northeast of Anaktuvuk Pass, which had very few sheep in previous surveys.

Mean search times for both low- and high-intensity surveys varied among the 3 study areas (Table 1). Ratios of low-intensity to high-intensity search time were similar in Unit 20A and the DCUA, as were SCFs, but values for both parameters were lower in Gates of the Arctic (Table 1). We counted more sheep in high-intensity helicopter searches than fixed-wing searches in 15/17 sample units in Unit 20A, 9/9 in the DCUA, and 22/34 in Gates of the Arctic. Total helicopter counts were higher than fixed-wing counts for the same areas in all 3 study areas (Table 1). We estimated 1942 sheep ± 17% (90% CI) in Unit 20A, 1673 ± 14 in the DCUA, and 2758 ± 8% in Gates of the Arctic. Again, we stress these figures are not true sheep population estimates, but estimates of sheep we would have counted if we had searched entirely at high-intensity by helicopter.

Confidence intervals around ram:ewe or ram:"ewelike" ratio estimates were wide in all study areas, even though we classified 38% to 52% of the estimated population in each area (Tables 5, 6, and 7).

DISCUSSION

SURVEY METHODS

Heimer and Watson (1982) concluded that Supercubs were better survey aircraft than helicopters. Their argument was based partly on cost-effectiveness; operating costs for turbine helicopters are 3 to 4 times as much per hour as Supercubs, requiring that turbine helicopter surveys locate many more sheep per hour to be cost-effective. Because they saw more sheep per hour from a less expensive Supercub, Heimer and Watson (1982) concluded that helicopters were undesirable for surveying sheep. We have reexamined the original data upon which Heimer and Watson (1982) based their conclusion. They compared 2 fixed-wing surveys and 1 helicopter count of the same area. The first fixed-wing count occurred 12 weeks before the other surveys. During 1995 and 1996 radiocollared lambs moved into and out of the same area during the comparable time period (B Scotton, pers commun). Therefore, the same number of sheep may not have been available for all 3 counts. Also, rams were not classified by horn curl in the first and apparently most efficient (in terms of both sheep/hr and dollars/sheep) fixed-wing survey, and the so-called less efficient surveys expended an unknown amount of extra time in circling and classifying rams. The extra time did not result in more sheep seen but it did provide additional information. Finally, the helicopter survey tallied the highest absolute number of sheep, 2.41 times the second fixed-wing count which occurred 1 week later. Because of these discrepancies, we question the conclusion by Heimer and Watson (1982) that helicopters are not suitable for surveying sheep. Researchers in Denali and Wrangell/St. Elias National Park and Preserve also compared aircraft types and concluded that helicopters were superior vehicles for counting sheep (Singer et al. 1981, Strickland et al. 1992*b*).

We saw more sheep during high-intensity searches than during low-intensity searches in all 3 study areas, in part because we spent more time looking for sheep in the high-intensity searches. Also, all observers in this study who flew in both aircraft types (n = 7) felt sightability of sheep was higher from helicopters because of greater forward and sideways visibility, slower flying speed, and higher maneuverability than Supercubs. This sentiment was shared by our main helicopter pilot (R Swisher), who has extensive experience as a fixed-wing survey pilot. Increased maneuverability in helicopters enabled us to fly more closely to terrain and make tighter turns, allowing a constant view of terrain. Fixed-wing aircraft frequently made climbing or descending turns over valleys to set up safe approaches for counting sheep in narrow side canyons or on cliffs, which took time away from actively searching for sheep.

We strove for consistency of effort in both high- and low-intensity searches. Minutes per km^2 of map area, however, was not an accurate measure of true search effort because it did not account for terrain complexity. Deep valleys and rugged canyons had more surface area than gentle slopes or low ridges and took longer to survey. Thus, the higher, more rugged mountains of the DCUA required longer search times for both fixed-wing and helicopter counts than the gentler terrain of Unit 20A. Ratios of mean fixed-wing search intensity to helicopter search intensity were nearly identical in both areas, as were SCFs (Table 1), indicating search efforts were consistent even though search times per unit area varied.

Fixed-wing search intensity in Gates of the Arctic was intermediate in comparison to the 2 previous surveys, as was terrain complexity. However, helicopter search time was lower in Gates of the Arctic than in the other study areas, resulting in a lower ratio of fixed-wing time to helicopter time (Table 1). Two factors may have contributed to our failure to maintain consistent high-intensity search effort relative to low-intensity effort in Gates of the Arctic. First, the study area was very large, and frequent weather delays throughout the survey caused us to hurry helicopter searches (we had additional fixed-wing aircraft available, so there was less perceived need to rush fixed-wing counts). Secondly, most sheep in the eastern part of the Gates of the Arctic study area were concentrated on the highest ridges where we spent more search effort. We should have searched cliffs and canyon bottoms thoroughly.

Lower SCF in the Gates of the Arctic survey (Table 1) was largely attributable to our failure to maintain adequate high-intensity search effort. Also contributing to lower SCF in Gates of the Arctic was the presence of many sheep on ridgetops, where slower speed and higher maneuverability of the helicopter was not a particular advantage in spotting sheep. In contrast, sheep in Unit 20A and the DCUA were more evenly scattered across elevations, including canyon bottoms and cliffs where helicopters would most likely outperform fixed-wings.

Maintaining adequate and consistent search intensities should be a priority in all surveys. Pitfalls of failing to maintain survey consistency can also be illustrated by comparing results from our Gates of the Arctic survey in which we tried to maintain consistent search effort to previous surveys in which search effort varied (Tables 2, 3, and 4). For discrete areas of our Gates of the Arctic study area (i.e., clusters of our 1996 sample units), we divided the number of sheep we estimated by the number counted in previous surveys and compared that ratio to time we spent searching divided by time spent in previous surveys (Fig 1). The more time we spent relative to earlier counts, the more sheep we estimated. The implication is that previous surveyors counted a higher proportion of sheep in some areas than in others.

Our population estimates are not true estimates of sheep in our study areas, but of sheep we would have counted had the entire survey been done at high intensity by helicopter. Other studies have indicated a point of diminishing returns beyond which increasing fixed-wing search effort ceases to result in more sheep seen. Strickland et al. (1992*a*) reported observers in Supercubs saw 22% more sheep when searching at 1.2 min/km^2 than at 0.4 min/km^2, but searching at 2.3 min/km^2 resulted in no further increases. McDonald et al. (1990) counted 16% more sheep at 2.5 min/km^2 than at 1.0 min/km^2, with most of the difference coming from areas of particularly complex terrain. Thus, the point of diminishing returns for Supercub surveys was about 1.2 min/km^2, or perhaps somewhat higher in complex terrain. Our fixed-wing search intensities were intermediate between the low-intensity search efforts of McDonald et al. (1990) and Strickland et al. (1992*a*), to which 16% and 22% more sheep were added by increasing intensity to the point of diminishing returns. In Unit 20A and the DCUA we saw 33% to 38% more sheep in our high-intensity helicopter searches. Thus, we are confident our population estimates for Unit 20A and the DCUA are higher and more realistic than any counts we could have obtained by intensive fixed-wing aerial survey alone.

In Gates of the Arctic we saw only 11% more sheep in our high-intensity searches. Our fixed-wing search intensity was roughly comparable to the Unit 20A and DCUA surveys, but our helicopter search time was lower (Table 1). We probably were not estimating as many sheep as we should have. We might have duplicated our population estimate by increasing fixed-wing search intensity 50% (i.e., to about the point of diminishing returns), but we could probably have raised it by increasing helicopter search intensity 15% to make the ratio of fixed-wing search effort to helicopter search effort comparable to our other surveys. Based on an R-22 helicopter operating cost of approximately 1.5 times that of a Supercub, the latter option would have been cheaper, as well as offering a higher and more realistic population estimate. Previous large scale surveys of Gates of the Arctic used helicopters, at the same or lower search intensities as our 1996 survey. Therefore, our 1996 estimate, while not as reliable as our estimates for Unit 20A and the DCUA, should still be as high or higher a proportion of sheep actually present than was counted in previous surveys of Gates of the Arctic.

We do not know what proportion of sheep we saw in our high-intensity helicopter searches. Researchers have occasionally used collared sheep to determine mark-recapture SCF for intensive fixed-wing surveys. Heimer and Watson (1986) reported seeing 48/63 collared sheep (76%; SCF = 1.31) in a Supercub survey of 1.3 min/km^2. Heimer and Watson (1986) also reported seeing 83% of the collared sheep in another Supercub survey of 0.9 min/km^2. However, original data files from that survey were unclear as to how many collared sheep were present in the population and which collars were found by radiotracking only (i.e., not truly "recaptured" in the visual count). Sightability may have been as low as 71% (60/85 versus 68/82; SCF = 1.41 and 1.21, respectively). In another survey (ADF&G, unpubl files, Fairbanks) confusion over the number of collars available resulted in sightability between 62% and 78% (57/92 versus 57/73; SCF = 1.61 and 1.28, respectively). Mauer and Whitten (FWS, unpubl files) found 24/28 radiocollared sheep (86%; SCF = 1.17) in a Supercub survey of 1.0 min/km^2; however, 3 of the 24 collars were not detected visually, even though the sheep wearing them were definitely seen and counted during the survey (based on other collared sheep in the same groups). Apparent efficiency (based on collars actually recorded) would have been only 75% (SCF = 1.33). Collectively, these surveys indicate that efficiency for intensive fixed-wing surveys is about 70% to 80% (SCF = 1.25-1.43), but may be slightly higher if observers are seeing some sheep whose collars are undetected. We were probably achieving this level of efficiency in our Gates of the Arctic helicopter searches, but undoubtedly exceeded it in our Unit 20A and DCUA helicopter counts.

Alternative double-counting statistical techniques could potentially account for the unknown efficiency of our high-intensity helicopter counts. When 2 aircraft survey the same areas, groups of sheep seen by only 1 aircraft or by both can be compared statistically and a total number of sheep estimated which takes into account SCF for both planes (McDonald et al. 1990; Strickland et al. 1992*a,b*). We found that sheep movement, joining or fragmenting of groups between flights, and mapping discrepancies made it difficult, and sometimes impossible, to objectively determine which groups of sheep were the same in consecutive surveys. Adjusting helicopter count totals by extra sheep presumably seen only by fixed-wing (i.e., fixed-wing count for a sample unit exceeded the helicopter total) would result in SCFs for high-intensity surveys of 1.02 in Unit 20A and 1.07 in Gates of the Arctic. No known additional sheep were seen by fixed-wing only in the DCUA survey. Double-count statistical surveys of Dall sheep elsewhere in Alaska yielded population estimates with confidence intervals ranging from ± 19% (80% CI) to ± 24% (95% CI) (McDonald et al. 1990; Strickland et al. 1992*a,b*). Our simpler method required no subjective decisions and yielded CIs of ± 8% to 17% at the 90% level. In fairness, however, our search intensities for both fixed-wing and helicopter counts were also much higher.

POPULATION TRENDS

Unit 20A

McNay (1990) reported up to 5000 sheep in Unit 20A in 1989, basing his estimate on an assumption of continuous growth since 3576 sheep were supposedly counted in a unitwide survey in 1977 (WE Heimer, ADF&G, unpubl files). However, Heimer's count was actually a composite from Supercub surveys flown mostly in 1973 but with some areas counted in 1970 or 1975. Search intensity for Heimer's count was 0.76 min/km^2, almost identical to our low-intensity survey in Unit 20A (Table 1). Sheep reportedly declined during the mid-1970s, so the basis for McNay's extrapolations was unrealistic. Nevertheless, our estimate of 1942 sheep ± 17% clearly represents far fewer sheep in Unit 20A in 1994 than in the recent past (Whitten and Eagan 1995).

Chronic low recruitment was a factor in the decline of sheep in Unit 20A (Eagan 1993). The lamb:"ewelike" ratio we observed in 1994 (50:100 ± 11%; Table 5) indicated recruitment was beginning to improve. This trend was confirmed by ratios of 44 lambs:100 ewes and 24 yearlings:100 ewes in helicopter surveys of a small portion of the unit in early June 1995 and 51 lambs:100 ewes and 35 yearlings:100 ewes in 1996 (Scotton 1996; ADF&G, unpubl files).

DCUA

We estimated 1673 sheep ± 14% in the DCUA in 1995 (Whitten 1996). Previous intensive fixed-wing surveys (ca. 1.2 min/km^2) of a trend count area within the DCUA indicated 604 adults (i.e., nonlambs) in 1974, 473 in 1975, 450 in 1980, and 614 in 1992 (DuBois 1993). Our low-intensity (0.9 min/km^2) count of the trend area in 1995 was 472 adults, and the estimated number of adult sheep that would have been counted in a high-intensity helicopter search was 614 (90% CI = 528-700 adults). Had we done a high-intensity fixed-wing count of the trend area in 1995, we should have seen between 472 and 614 sheep. Thus, sheep in the DCUA in 1995 were probably about as abundant as they had been 10 to 20 years previously, but less numerous than in the early 1970s and early 1990s. Only 14% of rams in the DCUA were ≤ half curl in 1995 (Table 6), indicating poor recruitment and corroborating a recent decline. The decline was probably not as severe as in adjacent Unit 20A, where chronic low recruitment led to as few as 3% rams ≤ half curl in 1992 (Eagan 1993). Sheep in the DCUA were probably increasing again in 1995, with 18% lambs and 9% yearlings.

Gates of the Arctic

The current sheep population in Gates of the Arctic probably does not differ markedly from the population in the early to mid-1970s and early 1990s, although variable count areas and survey methodologies make direct comparisons with previous surveys impossible. We counted 350 sheep by Supercub in an area (sample units 1-11) where 369 sheep were counted in a Supercub survey of unknown intensity during 1970. Fixed-wing counts in 1974 varied widely in search intensity. In 2 areas where our fixed-wing search effort was 1.4 to 2.1 times greater than in 1974, we counted fewer sheep (Table 2). In another area where we flew 3 times more intensively than in 1974, we saw more sheep. Where the 1974 counts were higher, all sheep habitat in the search unit was covered. Where the 1996 count was higher, the earlier survey had covered only a small portion of potential sheep habitat. We counted a few more sheep in Supercub surveys in 1996 than were counted in helicopter surveys of the same sample units in 1993, but we also spent more time searching (Table 3).

Clearly, however, sheep are now far less abundant than they were 10 to 15 years ago. We estimated substantially fewer sheep than a helicopter survey of our entire study area in 1982-1983 and also far fewer than a helicopter count of a portion of our study area in 1987 (Table 4). When we surveyed 50% to 130% more intensively than Singer, we estimated 25% to 50% fewer sheep. When our search intensity was only 25% to 50% greater than Singer's, we estimated 50% to 75% fewer sheep. Overall, sheep in our Gates of the Arctic study area in 1996 were probably < 50% as abundant as when Singer surveyed the area in 1982-1983. Our 1996 search intensity was about the same as Adams' (1988), and we estimated about 65% fewer sheep (Table 4).

Singer (1984) reported an increase of 22% (11%/yr) in 3 areas he counted in 1982 and 1984. Adams (1988) reported a 27% increase (5%/yr) for sheep in those 3 areas between Singer's 1982 counts and his own 1987 surveys and pointed out that variation in survey intensity, as well as actual population growth, could account for the difference. However, Adams' (1988) figures for the 1982 counts differed from Singer's (1984) numbers. Examination of original survey records indicates that Singer's figures were correct. In that case, sheep increased 11%/yr between 1982 and 1984, were stable between 1984 and 1987, and declined 66% by 1996 (Table 4).

This scenario for sheep population trends in Gates of the Arctic is roughly similar to an area in the Arctic National Wildlife Refuge in the eastern Brooks Range. Sheep counted in intensive fixed-wing surveys of the Hulahula drainage increased from 1746 in 1976 to 3193 in 1986 (83%, or 6%/yr) and then declined 52% to 1522 in 1993 (Mauer, pers commun).

COMPOSITION ESTIMATIONS

Sheep social behavior leads to sexual segregation of rams and ewes and formation of maternal and nonmaternal bands of ewes (Geist 1971). Thus, entire valleys or ridges are often inhabited predominantly by a single type of sheep social group, and wide confidence intervals around our estimates of composition ratios reflect this natural variation (Table 5). Counting a high proportion of sample units would be necessary to reduce sampling variance in estimates of adult sex ratio. Some yearlings join male groups or form groups of their own. Yearling:ewe ratio estimates also had wide confidence intervals, though not as wide as ram:ewe ratios (Table 5). Confidence intervals in lamb:ewe ratios were generally narrower. While ewes may segregate into maternal versus nonmaternal groups, these groups occupy the same ranges and are not as geographically separated as rams. Larger numbers of sample units in Unit 20A and Gates of the Arctic contributed to generally narrower confidence intervals for all ratio estimates in those study areas.

HARVEST AND OTHER FACTORS AFFECTING POPULATION TRENDS

Before our surveys, hunting pressure had been high in Unit 20A and moderate in the DCUA and the Preserve portion of our Gates of the Arctic study area. The bag limit in these areas was 1 full-curl ram and the season was 10 August to 20 September. In the Park portion of Gates of the Arctic, hunting was restricted to federally qualified local residents (almost exclusively residents of Anaktuvuk Pass in the areas we surveyed) with a bag limit of 3 sheep of either sex and a season from 1 August to 30 April. Full-curl (Class IV) rams were relatively abundant, composing 24% to 30% of rams and 5% to 7% of all sheep classified in all study areas (Tables 6 and 7). In Gates of the Arctic, full-curls composed 29% of rams in the preserve, 28% in the park, and 6% of all sheep in both areas. Consequently, hunting had no discernible affect on ram abundance in any of our study areas. We estimated 1100 sheep (955 adults and yearlings) remaining in areas hunted by residents of Anaktuvuk Pass. If recent high lamb productivity and survival continue, traditional harvests of 20 to 30 sheep by Anaktuvuk can be safely supported or even increased, so long as harvest remains mostly rams.

Recent sheep population declines in all study areas correlate with severe, deep snowfall winters between about 1988 and 1993. Predators, especially wolves, were abundant in all areas and have been suggested by many members of the public as important factors in the declines. Chronic low recruitment affected both sheep and caribou in Unit 20A beginning in 1989 (Eagan 1993, Boertje et al. 1996). Caribou pregnancy rates declined significantly (to 30%) in 1993 after a particularly severe winter (Boertje et al. 1996), and only 12 lambs:100 ewes were observed shortly after lambing that year (Dale 1996). Wolves were reduced through department control from late 1993 through late 1994 but recovered rapidly after control efforts ceased. Predation remained a major factor limiting caribou recruitment in Unit 20A through 1996 (Valkenburg 1996). In contrast, lamb recruitment began to recover by 1994, and a lamb mortality study in 1995 and 1996 confirmed high survival with low rates of predation compared to caribou calves (Scotton 1996). Sheep in the DCUA and Gates of the

Arctic also show signs of population recovery in recent years of relatively mild winters with no changes in wolf densities or harvest regulations.

MANAGEMENT RECOMMENDATIONS

Our technique of using high-intensity helicopter searches to determine a sightability correction factor for inexpensive low-intensity fixed-wing surveys proved promising for providing statistically bounded estimates of Dall sheep populations. Success of this technique requires careful planning and strict adherence to survey protocols. Careful mapping of sample units to minimize sheep movements across boundaries is particularly important, as is maintaining consistent search intensities. We probably underestimated the current sheep population in Gates of the Arctic by failing to maintain sufficient high-intensity effort.

Our technique had several advantages over standard fixed-wing searches. By flying at relatively low intensity and minimizing composition counting (i.e., classifying only adults and lambs), we avoided flying close to dangerous terrain and making multiple passes over groups of sheep in difficult areas to sort out yearlings, young rams, and/or ram horn-curl classes. This enhanced safety and also increased efficiency by allowing us to spend relatively more of our fixed-wing flight time searching as opposed to setting up approaches over bands of sheep. With the helicopter we could safely obtain more detailed and accurate composition data than in fixed-wing aerial surveys. In Gates of the Arctic, we found we could comfortably survey with the helicopter in winds and turbulence that forced Supercubs to return to base.

The R-22 piston helicopter we used costs 1.5 times as much per hour as a Supercub. Optimal high-intensity search effort (i.e., 1.4 times low-intensity search effort, as in the Unit 20A and DCUA surveys) costs about twice as much per km^2 as our low-intensity Supercub surveys. We would still find more sheep/dollar by increasing Supercub search intensity roughly 50% to the point of diminishing returns for fixed-wing surveys. However, increasing fixed-wing search effort beyond that point would rapidly mount up costs and probably never find as many sheep as optimal helicopter search effort. Thus, when finding as many sheep as possible is important, the cheaper cost of a Supercub proves to be false economy.

Our technique is particularly attractive for estimating sheep numbers in large study areas. It takes advantage of the ready availability and relative economy of small, high-performance fixed-wing aircraft and more efficient (for spotting sheep) but more expensive helicopters. For very large areas, the proportion of the study area flown by helicopter (i.e., sightability correction and composition plots) can be varied or optimized to fit a budget. The technique is also adaptable to extrapolation estimations in which fixed-wing surveys cover a random sample of survey plots in the study area. All applications of our technique yield a statistically bounded estimate of the number of sheep that would be found in a complete survey of the study area by high-intensity helicopter search. Helicopter searches do not find all sheep present in an area, but if observers maintain sufficient search intensity, the rate of underestimation should be consistent and, presumably, small.

For smaller survey areas, the R-22 helicopter may prove the survey vehicle of choice because of its high efficiency and only moderately higher cost. Turbine helicopters are generally 3 to 4 times more expensive to operate than Supercubs and may be cost-prohibitive for much general survey work. Also, turbine helicopters burn jet fuel, which is often unavailable in remote villages and complicates logistics for remote area surveys. The R-22 piston helicopter burns the same widely available aviation fuel as Supercubs and most other small fixed-wing aircraft.

Bleich et al. (1994) cautioned that intensive surveying with helicopters can drive sheep out of count areas before they are seen or cause sheep to flee far enough and fast enough that they are counted in more than 1 sample unit. Heimer and Watson (1982) also cautioned that sheep may try to evade helicopters. The R-22 piston helicopter is considerably quieter than turbine helicopters and probably causes less disturbance. Also, careful delineation of sample units so that boundaries form natural barriers to sheep movement (at least on a time frame of min to a few hrs) can greatly reduce the problem of sheep moving among sample units during a survey. Most Dall sheep summer habitat lacks trees or tall brush where sheep could truly hide from aircraft. Rock overhangs may conceal sheep from aircraft flying high overhead, but helicopters and sometimes even Supercubs can fly low enough to look back under overhangs or into crevices. In Gates of the Arctic, we sometimes found sheep in caves, but a close pass with the helicopter usually caused sheep to exit, often bringing other sheep with them. We may still have missed some sheep in caves, but the helicopter was more efficient than fixed-wing aircraft in alleviating this problem.

As a final caution, anyone working with Dall sheep in Alaska should be wary of historical survey data. Many past surveys did not maintain consistent search intensity or consider the possibility of sheep moving across sample unit boundaries during surveys. Published summaries usually treat all survey results equally and make no adjustments for differences in methodology from area to area or year to year. No one should use sightability data from this study to adjust past records without carefully examining original survey documents and maps. Even then, missing data on search effort will often preclude comparisons of past and present surveys, except in a very qualitative sense.

ACKNOWLEDGMENTS

TA Boudreau, R Brubaker, BW Dale, N Dema, SD DuBois, RM Eagan, M Keech, S Pedersen, R Riesgaard, BD Scotton, and J Woolington acted as fixed-wing and/or helicopter observers. JM Ver Hoef helped with aerial observations and also provided statistical advice. A Hamilton, W Lentsch, DC Miller, J Rood, TM Webb, and H Weiler piloted Supercub aircraft. R Swisher and T Cambier flew helicopters. D Thompson of Denali Wilderness Lodge and W Waugaman provided logistical support during the Unit 20A survey. The National Park Service provided all operational funding and logistical support for the Gates of the Arctic survey.

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PREPARED BY:

Kenneth R Whitten
Wildlife Biologist IV

SUBMITTED BY:

Kenneth R Whitten
Research Coordinator

APPROVED BY:

Wayne L Regelin, Director
Division of Wildlife Conservation

Steven R Peterson, Senior Staff Biologist
Division of Wildlife Conservation

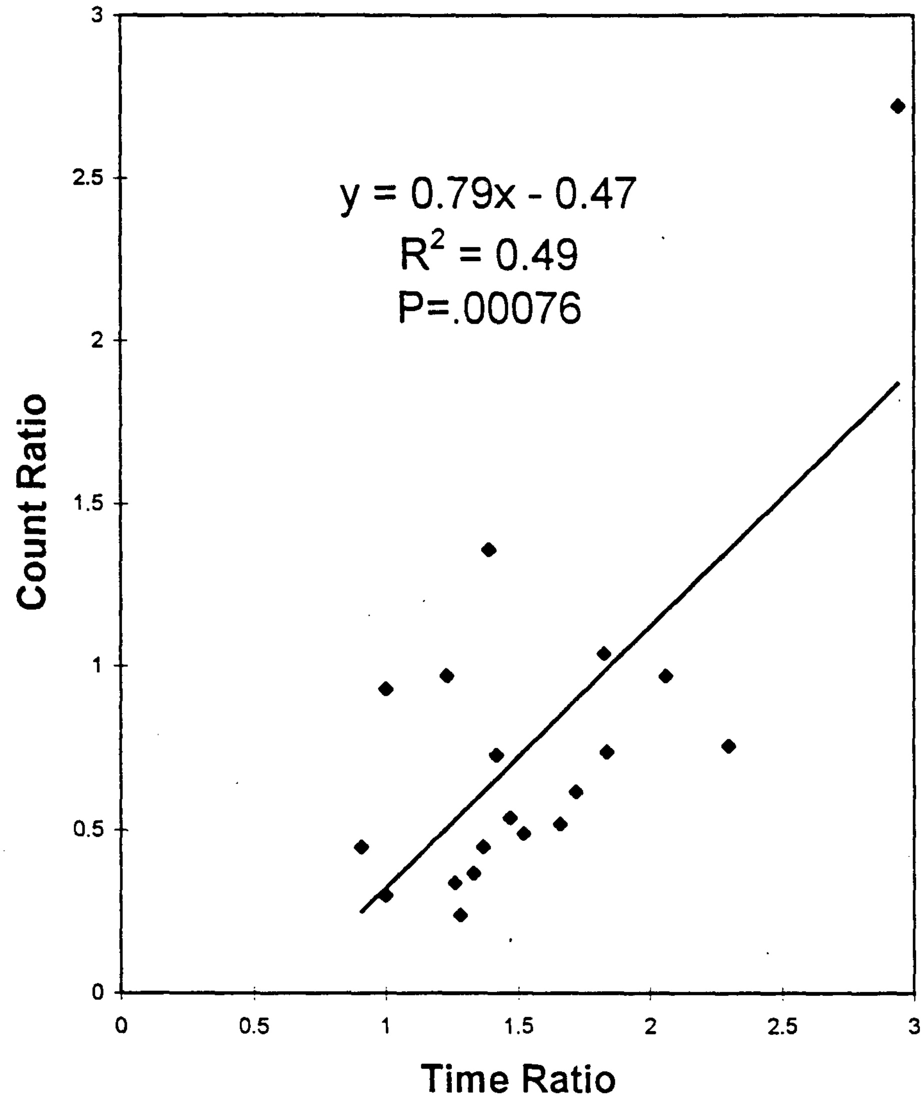

Figure 1 Comparison of 1996 Dall sheep survey results with previous survey results, Gates of the Arctic National Park and Preserve, Alaska. Time ratio is 1996 time divided by previous survey time. Count ratio is 1996 count divided by previous survey count.

Table 1 Fixed-wing and helicopter search intensities and sightability correction factors for Dall sheep surveys in Unit 20A, the Delta Controlled Use Area, and Gates of the Arctic National Park and Preserve, Alaska

	Search Intensity (min/km^2)			Sightability
Area	Fixed-wing	Helicopter	Helicopter:Fixed-wing	correction factor
Unit 20A	0.74	1.05	1.42	1.34
DCUA	0.93	1.34	1.44	1.30
Gates of the Arctic	0.80	0.97	1.21	1.10

Table 2 Search times and of numbers of sheep counted during fixed-wing surveys of Dall sheep in 1996 versus 1974[a] in Gates of the Arctic National Park and Preserve, Alaska

	Time (min)		Number of sheep	
Sample units	1996	1974	1996	1974
63-67			46	56
53-62	555	270	251	258
47-52			158	103
36,40,41,44-46	370	126	275	101
18,19,20	149	105	85	116

[a] Alaska Department of Fish and Game, unpubl files.

Table 3 Search times and numbers of sheep counted and during fixed-wing surveys of Dall sheep in 1996 versus helicopter (Robinson R-22) surveys in 1993[a] in Gates of the Arctic National Park and Preserve, Alaska

	Time (min)		Number of sheep	
Sample units	1996	1993	1996	1993
89-93	267	192	178	131
76-87	514	417	206	213
68-75	232	231	75	81
57-62	304	166	200	192

[a] Osborne 1996.

Table 4 Search times and numbers of sheep estimated during fixed-wing/helicopter (Robinson R-22) surveys of Dall sheep in 1996[a] versus search times and numbers of sheep counted during helicopter (Bell Jet Ranger) surveys during 1982[b], 1984[b], and 1987[c] in Gates of the Arctic National Park and Preserve, Alaska

	Time (min)			Number of sheep			
Sample units	1996	1987	1982	1996	1987	1984	1982
89-93	298		180	184			354
76-87	622	666	408	227	666	578	462
68-75	280	414	210	80	264	237	216
63-67	230	213	180	51	113	264	210
53-62	590		402	271			501
47-52	388		225	206			334
21-46	1722		750	1100			1456
12-20	555		405	250			551
1-11	755		410	385			521

[a] 1996 estimates were calculated by multiplying sheep in sample units surveyed by fixed-wing by a sightability correction factor of 1.11 and multiplying fixed-wing search times by 1.21 to simulate a survey done completely by helicopter.
[b] Singer 1984.
[c] Adams 1988.

Table 5 Composition and population size estimates from fixed-wing/helicopter surveys of Dall sheep in Unit 20A, the Delta Controlled Use Area, and Gates of the Arctic National Park and Preserve, Alaska

Area	Lambs:100 Ewes	Yrlgs:100 Ewes	Rams:100 Ewes	Population estimate
Unit 20A	50 ±11%[a]		42 ±17%[a]	1942 ±17%
DCUA	37 ±20%	19 ±28%	50 ±46%	1673 ±14%
Gates of the Arctic	47 ±9%	25 ±16%	43 ±17%	2758 ±8%

[a] Unit 20A ratios are :100 "Ewelikes" (i.e., ewes, yearlings, and 1/4-curl rams).

Table 6 Dall sheep sex/age classifications from intensive helicopter surveys in the Delta Controlled Use Area and Gates of the Arctic National Park and Preserve, Alaska

Area	Ewes	Lambs	Yrlgs	Rams[a] I-II	Rams[a] III	Rams[a] IV	Total
DCUA	312	115	59	21	87	47	641
Gates of the Arctic	658	318	171	107	95	81	1430

[a] Horn curl classes (after Geist 1971): I-II = < 3/4-curl; III = 3/4-7/8-curl; IV = full-curl.

Table 7 Dall sheep sex/age classifications from intensive helicopter searches in Unit 20A, Alaska

Ewelikes[b]	Lambs	Rams[a] I-III	Rams[a] IV	Rams[a] Unk	Total
408	203	120	38	13	782

[a] Horn curl classes (after Geist 1971): I-III = < full-curl; IV = full-curl.

[b] Includes yearlings and 1/4-curl rams.

Alaska's Game Management Units