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AERIAL SURVEY AND DALL SHEEP POPULATION SIZE: COMPARATIVE USEFULNESS OF EXTERNAL AND INTERNAL POPULATION DYNAMICS FOR MANAGEMENT PURPOSES

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Abstract: Survey flights over Dall sheep (*Ovis dalli*) ranges are the traditional and typical extent of population data collection for this species in Alaska. Many factors which introduce variability in these aerial surveys have been identified, and managers have often been reluctant to act based on these vaguely variable data. Development of statistical techniques to place bounds about Dall sheep population estimates offered some hope for greater confidence in Dall sheep survey data. However, the promise of these techniques is yet to be realized in Alaska. In the context of practical management, statistical confidence in the validity of population estimates is of secondary importance to the fact that even the best aerial population size estimates fail to elucidate internal population dynamics. The internal dynamics of composition and mortality effectively predict or explain fluctuations in population size and realizable harvests while total population estimates simply reflect changes which have already taken place. Even given accurate annual population estimates with statistically valid confidence limits, total population estimation techniques chronicle past population changes, and track them with an accuracy which is barely narrower than the recorded range of population fluctuations. This paper demonstrates the efficacy of using internal dynamics from previously published data, and discusses the disadvantages of strict reliance on aerial survey data for management purposes. Recommendations for improvements in population trend assessment are offered.

Ideally, modern management of wild mountain sheep for maximum sustained use would be based on detailed knowledge of the size and internal dynamics (production, recruitment, age structure, and age/sex-specific mortality) of the sheep populations being managed. Historically, these data have been generally considered unobtainable or prohibitively expensive to gather. As a result, managers have "made do" with less specific information, simple estimates of population size and trend.

The dominant methodology for gathering sheep population size and trend information throughout North America has been aerial survey. In most cases, serial estimates of population size have been used to define population trends. Where population size has not been considered definable by aerial survey, sheep managers have "settled for" indices of population trend such as minimum numbers of sheep seen, sheep seen per hour of survey effort, trend in number of animals harvested, or range use indicators.

Aerial survey and census of wild mountain sheep are dominated by factors which introduce variability to the results. The most basic of these factors is the choice between fixed or rotary-wing aircraft. For Dall sheep in Alaska, experience defined the Piper PA-18 Supercub as the aircraft of choice more than 20 years ago, but sporadic efforts to develop helicopter use for sheep surveys still continue. Once aircraft type has been chosen, a hierarchy of factors affecting data quality becomes operative.

These factors range from those which are clearly controllable through those that are somewhat manageable to factors beyond direct control of the manager. Controllable factors include aircraft type and survey intensity (time spent per area). Factors which are somewhat manageable include pilot and observer experience, level of pilot effort, observer enthusiasm/attitude, and factors which are negotiable with the aircraft pilot (e.g., flight speed, aerial technique relating to flight routes and terrain, lighting aspect, and distance above ground level). Factors which are virtually unmanageable include weather, light conditions, and sheep distribution among habitats where sheep are easier or more difficult to see. Finally, the composite effect of other work schedules and priorities must be balanced with relatively narrow meteorological and biological "windows" during which survey conditions are ideal.

This constraint often necessitates compromises among the hierarchy of factors listed above, resulting in less-than-ideal survey conditions and raising further questions about the verity of results. This complicates decisions by the sheep manager and those involved in the management process at higher organizational levels. The result is that no one is compelled to believe any 2 aerial sheep counts are truly comparable or that they accurately represent the biological situation with respect to population size or trend.

In addition to the inherent variability just discussed, counting methodologies include counting as many sheep as possible while flying in the mountains, counts with rigorously-defined flight paths and search intensities, the use of marked animals to define discrete populations and survey efficiency, and elaborate statistical sampling schemes and biometric analyses. This evolutionary spectrum of techniques resulted from incremental efforts to increase the credibility of aerial survey results. Statistically driven sampling schemes have been the most recent and high-profile efforts to increase this credibility.

The biostatistical approach to increasing the credibility of a single population estimate produced by an aerial survey has required generation of statistical variance within internal subsets of the survey data and using this variance to calculate a confidence interval about the estimate. In essence, this procedure predicts the precision of a theoretical sample of population estimates which would result if the survey could be replicated. To date large-scale surveys have been impossible to replicate because of their expense and the fact that the uncontrollable variables listed above preclude survey duplication. Small-scale repeat surveys with high precision were reported by Nichols (1976), but this technique has not been widely applied.

In spite of the difficulty in establishing the accuracy of these procedures, considerable effort has gone into development of statistically bounded single population estimates for several Dall sheep populations in Alaska (McDonald et al. 1990, Strickland et al. 1992, Strickland et al. this symposium). While progress has been made in placing confidence intervals about the individual sheep population estimates, some estimates, particularly those in the Wrangell Mountains (Strickland et al. 1992), seem implausibly high. Additionally, developmental work on this technique has shown fiscal constraints limit the practicality of narrowing the confidence interval to less than approximately plus or minus 20% of the estimated population size at the 90% level of confidence, the typical measure of precision.

If the ideal data set for maximum sustained yield management should include not only population size but also measures of internal dynamics of the managed population (defined earlier), a complete survey and inventory program cannot be limited to aerial population estimates. This paper defines the differences in management utility between external population dynamics (derivable from aerial estimation of total population size) and internal population dynamics (as listed earlier). Additionally, results from 2 Dall sheep monitoring programs in Alaska will be compared. One program focused exclusively on annual aerial surveys. The other program also monitored internal population dynamics and checked the predicted changes in population size based on these dynamics against external population dynamics derived by a repeated aerial survey.

METHODS

External Population Dynamic Monitoring

External dynamics of sheep populations in the Chugach Mountains were monitored by annual survey flights from 1976 through 1993. D. Harkness maximized efforts to limit variability in data collection. In July of each year, the same highly experienced pilot/observer team, B. Wiederkehr and D. Harkness, conducted the survey using the same aircraft (a PA-18-Supercub). Survey intensity (time spent in the area) generally was consistent from year to year at about 6 hours of flight time ($\approx$0.75 min/km^2 [2 min/mi^2]). Aerial technique also was consistent over the course of data collection. During these surveys, the number of Dall sheep counted was recorded, with sheep identified as lambs, ewe-like sheep (which include ewes, yearlings, and young rams which still look like ewes when viewed from an airplane), and rams of legal size depending on applicable regulatory definition.

Integrated Population Monitoring Using Internal Population Dynamics

In July 1980 an initial ewe population size estimate using ewes marked with neckbands to assess observability was generated for the well-defined sheep ranges in the Robertson River study area (Heimer and Watson 1986a). This estimate was based on intense aerial searches (1.5 min/km^2

[4 min/mi^2]) using a PA-18-150hp Supercub with a highly experienced pilot/observer team - B. Lentsch and W. Heimer). During this census, sightability of ewe-like sheep was established at 76% based on resighting 48 of the possible 63 marked ewes present in the count area. The number of ewe-like sheep was corrected for ewe-like sheep-not-seen by expanding the total observed by the proportion of known marked ewes sighted.

The actual number of ewes among the estimated number of ewe-like sheep was calculated using ground-based observations of population composition. Sheep were classified as lambs, ewes, yearlings, and rams of Classes I-IV (Geist 1971) using 8X binoculars and 15-60X spotting scopes at distances of less than 33m (100 yds) at the main mineral lick in the study area during the last 2 weeks in June. Mortality among marked ewes was calculated from mineral lick resightings over the next 4 years (Heimer and Watson 1986a). These data were used to elucidate the effects of internal dynamics on ewe population size. They were entered into a simple (yearling recruitment "in"/ewe mortality "out") model to predict the true ewe population size prior to a second aerial count scheduled for July 1984.

In June 1983 and 1984, trapping and marking resumed using established methods (Heimer 1974, Heimer et al. 1980), and resulted in 74 marked ewes (including some yearlings) present in the population for the 1984 aerial survey. The 1984 aerial survey duplicated the 1980 count as exactly as possible, including the same aircraft and pilot/observer team, search intensity, flight routes, and mark/resighting methodology.

RESULTS

External Population Dynamic Monitoring

Numbers of ewe-like sheep, lambs, young rams, and legal rams were recorded for each survey (Table 1).

Integrated Population Monitoring Using Internal Population Dynamics

In 1980 resighting of 76% of the known neckband-marked ewe-like sheep in the population during an intense aerial search of the area was used to produce a population estimate of 588 ewe-like sheep. Using reconciled aerial search and ground composition data, the ewe population was calculated to contain 456 true ewes (of which 63, or 13.8% were marked) and 132 yearlings of both sexes. Half of these yearlings (66) were assumed to be females so the midsummer ewe population was estimated to be 522 ewes of all ages.

Beginning with this ewe population size, using the internal dynamics of the ewe population as input, the population model predicted a mid-summer 1984 population size estimate of 550 ewes (Table 2).

Observation of 62 of the possible 74 marked ewes during the aerial count of 1984 produced a sightability correction factor of 0.84. When reconciled with ground composition data from spring 1984, a corrected population size of 550 ewes was calculated, indicating we marked approximately 13% of the ewe population.

The population of 550 ewes estimated from aerial counting in 1984 was identical to the population size predicted from the population model.

DISCUSSION

The traditional aerial survey approach to Dall sheep population inventory should be recognized as a compromise between having no data and having the complete data set required for information-based management. Prior to the biological discoveries and technological advances which allow insight into internal population dynamics, aerial survey of almost any type was the most attractive alternative. It became the standard technique, and eventually the traditional one.

Aerial survey or population estimation serves best when rigorously pursued each year. Heimer (1992) argued that population trend cannot be used reliably without annual assessment because "noise" caused by variations in environmental resistance from year to year may falsely indicate trend (or stability) if population assessments are intermittent. The data in Table 1 represent the most outstanding example of aerial survey consistency available in Alaska. These data indicate a period of stability at about 1000 sheep (1976-1979), a period of growth (1979-1988), and a period of stability at about 2200 sheep (1989-present); the population appears to have doubled in size since 1979. During the increase, the number of ewe-like sheep counted increased from about 600 to about 1250. There is no doubt more sheep have been seen during later counts, but the cause or causes of these higher counts are uncertain. Possibilities, ranging from an actual population increase with $r = 0.09$ (which is theoretically possible) to increased

Table 1. Game Management Unit 14C (Chugach Mountains) Dall Sheep Survey Data 1976-1993 courtesy of D. Harkness, Alaska Department of Fish and Game.

Year	Ewe-like sheep	Lambs	Lambs:100 ewe-like sheep	Young rams	Legal rams
1976	609	130	21	152	86
1977[a]	621[b]	21	--	--[b]	34
1978	596	135	23	141	88
1979	514	161	31	143	85
1980	740	182	25	171	70
1981	820	239	29	151	82
1982	967	193	20	231	79
1983	1006	89	29	292	118
1984	1048	357	34	269	158
1985	979	294	30	299	138
1986	1206	356	30	329	172
1987	1228	352	29	427	162
1988	1219	334	27	379	204
1989	1355	387	29	456	214
1990	1224	259	21	440	218
1991	1228	410	33	416	228
1992	1324	344	26	419	235
1993	1200	259	22	360	203

[a] Poor counting conditions.

[b] Young rams included with ewe-like sheep due to poor counting conditions.

Note: Prior to 1979 legal rams were 3/4 curl, from 1979-1988 legal rams were 7/8 curl, from 1989-1993 any sheep was legal. In this table rams recorded as legal from 1989-1993 were 7/8 curl or larger.

Table 2. Ewe population sizes, female yearling recruitment and overall ewe mortality for Dall sheep in the Robertson River area of the Alaska Range 1980-1984.

Year	End of winter adult ewe population	Yearling ewe recruitment from previous year[a]	Summer ewe population size	Winter ewe mortality % (years)[b]
1980	456 adults +	66 yearling ewes = (from 1979)	522 ewes	0% (1980-1981)
1981	522 adults +	84 yearling ewes = (from 1980)	606 ewes	22% (1981-1982) (-133 ewes)
1982	473 adults +	85 yearling ewes = (from 1981)	558 ewes	2% (1982-1983) (-12 ewes)
1983	546 adults +	38 yearling ewes = (from 1982)	584 ewes	17% (1983-1984) (-99 ewes)
1984	485 adults +	65 yearling ewes = (from 1983)	550 ewes	

[a] Calculated by multiplying half of yearlings:100 ewes ratio by the number of hundreds of ewes (Heimer and Watson 1986a).

[b] Calculated from resighting of collared ewes at mineral lick (Heimer and Watson 1986a).

counting skills by the pilot/observer team, could account for the increase.

Unfortunately, because of the absence of yearling recruitment, age structure, and mortality data, these possibilities cannot be rigorously evaluated. However, an actual population size increase based on the lambs:100 ewe-like sheep ratios appears to be improbable.

Calculation of the lambs:100 ewe-like sheep ratios for the period of early stability (mean = 25 lambs:100 ewe-like sheep), population growth (mean = 28 lambs:100 ewe-like sheep), and stability at high population (mean = 26 lambs:100 ewe-like sheep) reveals a remarkable stability. This level of lamb production (an overall mean of 27 lambs:100 ewe-like sheep, range = 20-34) would scarcely be adequate to support more than population maintenance in other areas of Alaska (Heimer and Watson 1986a,b). If the increases in sheep counted accurately reflected an increase in population size, mortality from countable-aged lambs through old-aged ewes must have been consistently lower than ever recorded in a pristine ecosystem.

Use of simple Lotus input/output simulation indicates the population increase between 1979 and 1988 would have required internal dynamics equivalent to those listed below:

1. A constant recruitment of 40 yearlings:100 producing ewes (given the estimated number of ewes of reproductive age calculated from typical composition data for growing sheep populations by Heimer and Watson (1986b) and the approximately 600 ewe-like sheep counted at the end of the early stable period),
2. A constant mortality of 3% or less on all age classes of ewes from yearling age through age 12 years during the growth period, and
3. Few ewes survive past their twelfth winter.

These conditions would be unusual. Seldom have single-year yearling:100 ewe ratios been recorded at 40:100 in Alaska, and it is certainly impossible to average 40 yearlings:100 ewe-like sheep with a mean lambs:100 ewe-like sheep ratio of 27:100 with little or no ewe mortality.

Measured mortality among ewes under age 9 averages 3% per year under normal conditions on ideal continental ranges (Watson and Heimer 1984). Once ewes exceed 9 years of age, mortality increases to an average of 50% per year (Heimer 1973, Watson and Heimer 1984, Heimer and Watson 1986a). It is not unusual for ewes older than 12 years to produce lambs (Heimer and Watson 1986a). Still, production of lambs recorded in Table 1 appears inadequate to produce the observed population growth. The consistency of the lambs:100 ewe-like sheep ratios throughout the survey period, coupled with 2 periods of stability on either side of unprecedented growth, suggests either emigration or a dramatic increase in survey area or efficiency during the 1979-1988 period.

Aerial monitoring of sheep populations, along with the best possible aerial sheep classification, does not provide sufficient data to answer biological questions. Even if these population estimates had relatively narrow statistical bounds, the data would still provide no clue as to how the measured increase was achieved.

In the Chugach Mountains where these data were gathered, no biological harm resulted from this failure to account for or offer a hypothesis to explain the population increase. That is, the existing sheep management program was not compromised because these populations are managed under a restrictive permit system. Conversely, a great deal of management benefit accrued as a result of these annual surveys because the public was content with the level of effort on the part of its managers. Furthermore, other user-focused benefits resulted from the surveys as hunting opportunities were shared from managers to users.

However, in a more typical management situation with maximum sustained yield harvest as the management goal, determination of the cause (particularly if low mortality) could have made cropping of ewes an unusually attractive option in the absence of normal environmental resistance. Without biological insight to the mechanisms of internal population dynamics, such management actions can be implemented only at high risk.

In contrast, the integrated population monitoring program using aerial population estimation along with data on the internal dynamics of the monitored population produced remarkable agreement between predicted and estimated population sizes over a 4-year period in sheep populations of the Alaska Range. I caution the reader against the inference that the technique is without error. Still, the remarkable exact prediction of the ewe population size suggests use of internal population dynamic data to predict external population sizes is workable. The fact that 2 major population adjustments took place during this period further suggests the potential predictive power of this procedure. The more striking fluctuation was associated with the unusually difficult winter of 1981-1982 (Watson and Heimer 1984). Mortality during this winter centered on old-aged ewes which had already exceeded normal life expectancy. Because this internal dynamic was understood, the 22% decrease in ewe population during winter of 1981-1982 was interpretable as a normal population adjustment, loss of "lingering" cohorts of old ewes from the population, and not a catastrophic population crash. Management was simplified by this knowledge.

Annual assessment of population composition allowed accurate prediction of a relative scarcity of mature rams 7 years after the low yearling recruitment of 13 yearlings:100 ewes in spring 1983, even though the lamb production had been nominal (29 lambs:100 ewes) in spring 1982. Harvest from this count area is conservatively managed for trophy production by a limited entry lottery permit for full-curl (or 8-year-old) rams. Consequently, unexpected failure to meet an anticipated harvest goal 7 years later with attendant hunter dissatisfaction was precluded. Nevertheless, benefits accrued to both managers and the hunters because hunters were aware of the likelihood of slightly decreased trophy ram abundance before going afield in 1990. Because of constant presence of managers in the field and the intermittent aerial surveys, identical ancillary benefits produced by the exclusive aerial monitoring of external population dynamics in the Chugach Mountains were also produced by the integrated program.

This comparison suggests the integrated program is equivalent to simple aerial surveys for providing benefits for managers and users and superior for answering biological questions. This should not be surprising, it has long been understood that variations in cohort size will affect age structure (Murphy and Whitten 1976); and that older-aged cohorts are more vulnerable to mortality during difficult winters (Watson and Heimer 1984).

Still, the questions, "How much information is needed?" and "Can we afford to gather it?" must be asked. If management needs are limited to maintaining a visible presence as active managers of monitored populations, the traditional aerial survey program may suffice if human costs are not a consideration (see subsequent discussion). Similarly, if management objectives do not focus on maximum sustained yield to attain harvest objectives which may be compromised by occasional production or recruitment failures or unexpected mortality, aerial survey may be adequate. However, if accurate biological monitoring to predict harvest or adjust regulations for quantifiable management objectives is desirable, or if increasing biological knowledge is an objective of management, the integrated program will be more beneficial.

In spite of the benefits produced by monitoring external population dynamics, we should recognize that even the most sophisticated, accurate statistical sampling schemes can only provide more confidence in individual population estimates based on aerial survey data. Deciding whether this confidence is warranted requires examination of basic assumptions concerning precision and accuracy. As presently conceived and practiced, statistically bounded population estimates provide a theoretical inference of precision but no assurance of accuracy.

Precision defines the consistency of repeatable measurements, but does not necessarily assure the set of precise measurements is accurate - only that the measurements are consistent with each other. In their quest for accuracy, it seems that sheep managers and biometricians have assumed that measurements with an acceptably defined level of precision (90% confidence) will be accurate (Strickland et al. 1992). That is, biologists seem to have assumed that accuracy is a function of precision.

There is no assurance this assumption is correct, and the incredibly high population estimates for the Wrangell Mountains (Strickland et al. 1992) raise serious questions about their accuracy (although they are acceptably precise). Still, the assumption is understandably attractive because its converse is, by definition, true. It is mathematically certain that high precision is generated by repeatedly making accurate measurements of stable parameters. Hence, precision among measurements is a function of measurement accuracy if the measured parameter is static. At the present time, there is no actual link between the theoretical precision projected for an estimated Dall sheep population size and the accuracy of the population estimate. In the jargon of remote sensing, we would say, "There is no 'ground truth' for aerial survey data."

The lack of verification that bounded population estimates are accurate becomes disconcerting when we recall the assailability of Dall sheep count accuracy was the reason for development of statistically acceptable aerial sampling procedures in the first place. These circumstances define a curious relationship between perceived and actual accuracy, a relationship which managers may profitably reconsider.

Additionally, managers should recognize

inherent variability in sheep population size from year to year may exceed the projected resolution capability of the statistically bounded population estimate. Given that variations in Dall sheep populations of 20%-25% (Watson and Heimer 1984, Heimer 1992) can be independent of long-term population trend (Heimer 1992) without serious management consequence, it seems unlikely that continued statistical refinement of aerial population estimation techniques will realistically meet management needs. If sheep populations vary by plus or minus 20%-25% without severe management consequences, the management relevance of a very expensive technique having a 90% chance of documenting changes, which must be greater than plus or minus 20%, is unclear. Hence, the question of whether accuracy is a function of precision or vice versa becomes moot because inherent variability in population size from year to year may exceed the resolving power of the technique at any time.

The best we can hope for from biostatistical approaches to population estimation is an accurate (or perhaps precise) chronicle of external population dynamics and longer-term trend providing that population estimates are made with sufficiently high frequency. Even if such estimates were affordable and hence available, they do not hold the promise of allowing managers to accurately anticipate population changes which will affect future harvest success, changes which are certain to result from the internal dynamics of sheep populations.

Each approach has its unique costs. Monitoring external population dynamics from aircraft requires relatively large investments of operational funding, particularly if biologists use helicopters. Aerial survey also carries a little-recognized human cost. Flying in mountainous terrain is dangerous and takes a surprisingly high toll in the lives of managers and pilots.

The proceedings of this symposium list since 1970 the deaths of Jim Erickson and his pilot (fixed-wing Dall sheep survey-Alaska); Harold Mitchell, Wesley Prediger and their pilot (helicopter bighorn work-British Columbia); Orval Pall, his pilot, and another observer (fixed-wing bighorn radiotelemetry-Alberta). Other sheep and goat management-related deaths of which I am aware include Spencer Linderman and his pilot (fixed-wing goat survey-Alaska) and the deaths of 10 others engaged in aerial searches for missing biologists. These 20 deaths (and perhaps others) have taken place during the last 24 years. To be coldly mathematical, these data establish an average death rate associated with aerial counting of sheep and goats of 1 human life every 14.4 months. The hazard of flying near mountains is further illustrated by the even greater number of deaths among guides and hunters who also use aircraft to search the mountains for sheep and goats.

In contrast to aerial survey, the integrated program is less hazardous and requires scant operational funding but lavish expenditure of time. If professional managers were to spend the requisite amount of time on the ground with sheep, salary costs could exceed those of fixed-wing surveys, and perhaps approach those of helicopter use. However, I have had success limiting salary expenditures through the use of volunteers in capture operations and ground-based data gathering. There have been minor injuries associated with sheep capture, but the human (and fiscal) costs of ground-based methodology have been insignificant compared with aerial efforts. Some aerial survey is unavoidable in the integrated program, but the quality of information and the reduction in time spent at risk while flying in the mountains increases the benefits associated with the calculated risks of the required aerial counting to more acceptable levels.

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