Ram Horn Growth and Population Quality Their Significance to Dall Sheep Management in Alaska

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FRONT COVER:

UPPER: Very large Dall sheep ram in the Sheep Mountain Closed Area. (Photo by W. C. Gasaway)

LOWER: Horns from 7-year-old Dall rams reflect differences in quality. (Photo by W. E. Heimer)

RAM HORN GROWTH AND POPULATION QUALITY - THEIR SIGNIFICANCE TO DALL SHEEP MANAGEMENT IN ALASKA

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CONTENTS

INTRODUCTION

Wild sheep are considered by many to epitomize rugged wilderness and solitary grandeur of mountainous areas, and large rams rank among the highly prized game animals of the world. Although the wilderness character of their habitat is partially responsible for the high esteem in which they are held, most of their appeal to hunters and nonhunters alike is attributable to the size of their horns.

Alaska's Dall sheep *(Ovis dalli)* inhabit seven mountain ranges: Alaska Range east of Mt. McKinley (ARE), Alaska Range west of Mt. McKinley (ARW), Brooks Range (BRR), Chugach Mountains (CMR), Kenai Mountains (KMR), Talkeetna Mountains (TCW), Tanana Hills-White Mountains (THW) and the Wrangell Mountains (WMR) (Fig. 1). Through the years sheep hunters and biologists have believed that there are variations in conformation and size of sheep horns from these mountain ranges. To some extent records of horn sizes maintained by the Boone and Crockett Club (1971) confirm this belief, since most exceptionally large rams have been taken in the Wrangell and Chugach Mountains of Alaska. It must be recognized, however, that rare individuals reaching the unusually large size necessary for this recognition have come from most Dall sheep ranges, and rams listed in Boone and Crockett records are unusual animals far exceeding observed norms. The usefulness of records maintained by the Boone and Crockett Club for comparing sheep horn growth and conformation between mountain ranges is further limited because they do not contain information on age of the animal or horn increment length or other indications of growth rate. Data reflecting average rate of horn growth provide a much better indication of an area's capability for producing "trophy" rams.

Alaska Department of Fish and Game sheep management policies (ADF&G, 1972) recognize that recreational hunting is the dominant use of Dall sheep in much of the state. Because recreational quality and horn size are inseparable to many, it is apparent that with increased hunting pressure it will be necessary to manage selected portions of Alaska for the production of "trophy" rams. Areas chosen for "trophy" management must be those in which the inherent characteristics of sheep are compatible with this objective. For example, management for trophy production in an area where sheep have small, slow-growing horns would be impractical. Knowledge of rates of horn growth and expected horn size and conformation of sheep from various mountain ranges is, therefore, prerequisite to improved Dall sheep management.

Although limited data on the size of Alaska Dall sheep horns have been published previously (Scott, 1951; Hemming, 1967; Erickson, 1970 [and in Nichols and Erickson, 1969] and Boone and Crockett Club, 1971), necessary information for planning was previously unavailable. This paper provides a quantitative comparison of Dall sheep horn growth between and within mountain ranges in Alaska, suggests several possible explanations for variations in horn growth and discusses management implications of these findings.

Even though the primary objective of this study was to provide information for making planning decisions, it also provided data with which to test Geist's (1971) "Quality Hypothesis" for North American wild sheep populations as it applies to horn growth. Geist postulated, in part, that quality differences exist between sheep populations and high quality populations are characterized by more rapid horn growth and more massive horns at any given age than are populations exhibiting lower quality.

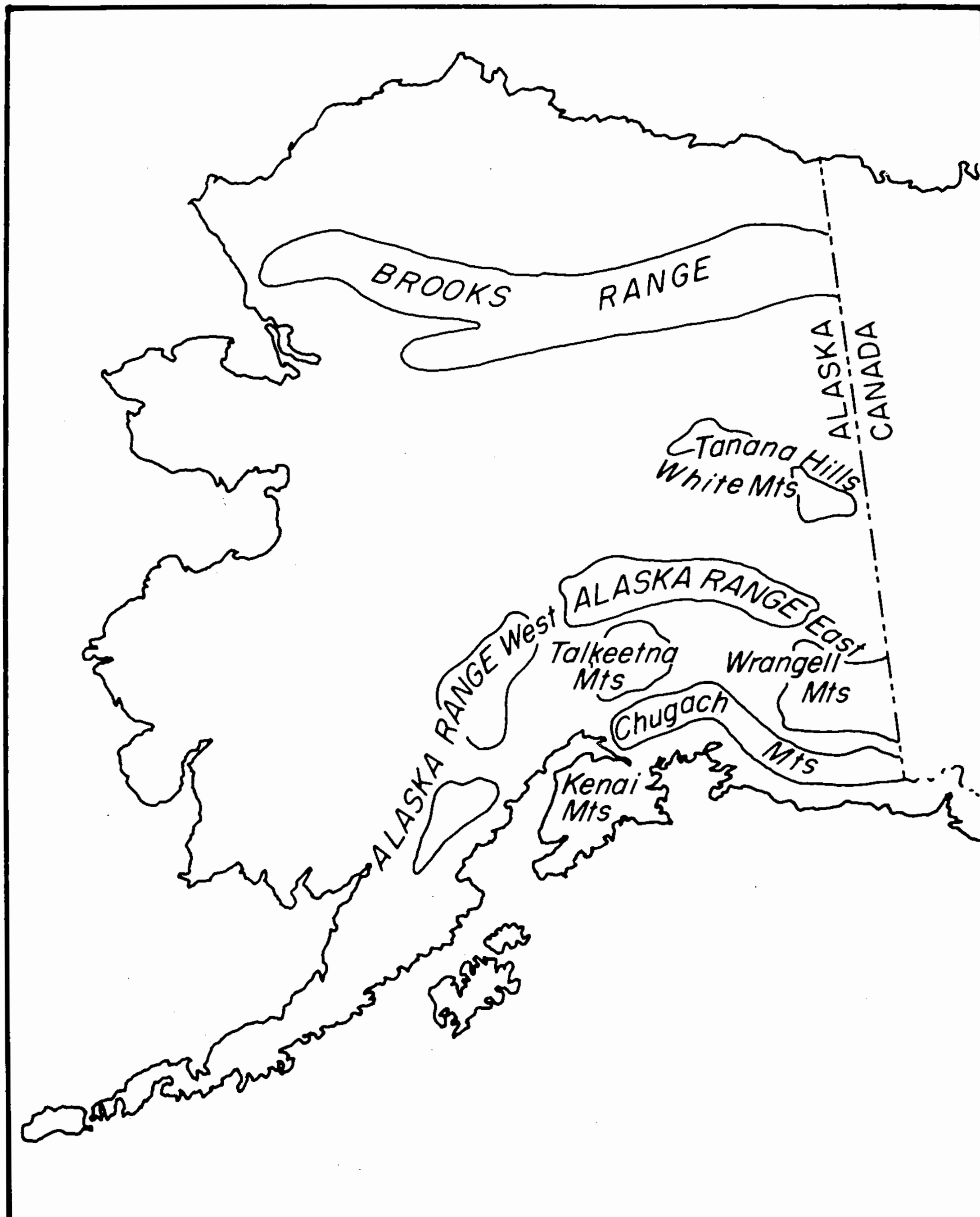


Fig. 1. Dall sheep ranges in Alaska.

HORN GROWTH AND POPULATION QUALITY

Methods and Materials

From 1968 through 1970 taxidermy shops throughout the state were visited, sheep horns measured and the addresses of successful hunters obtained. Hunters were then contacted by letter requesting the specific location where they had hunted. In this manner 570 sets of Dall ram horns were obtained for measurement. Additional specimens were obtained from hunters known to have taken sheep during other years from areas where hunter effort was low.

The age of each ram represented by a set of horns was determined by counting the annual growth segments according to the procedure of Geist (1966). Standardized measurements were made in the following manner: a flexible, steel measuring tape was attached with masking tape to the frontal surface of each horn and the lengths of all growth segments determined. The greatest diameter at the annulus of each segment was then measured using a vernier caliper, spanning the distance from the frontal surface to the nunchal edge as described by Severtzoff in 1873 (cited by Brooke and Brooke, 1875). Finally, the diameter of the circle described by the horn was measured on the 90°-270° plane at right angles to the axis of coiling with forestry-type calipers. All measurements were recorded in millimeters.

The volume of each horn was calculated from these linear measurements, assuming that the horn was a regular cone which had been bent into a spiral with no deformation, and that each annular segment was a frustum of the cone. The volume of each frustum was then calculated using the formula,

$$v = \frac{h}{3} \quad (r_1^2 + r_1 r_2 + r_2^2),$$

where r_1 and r_2 are the radii at the annuli describing the upper and lower limits of each frustum and "h" is the recorded segment length. Frustal volumes were summed to determine the total calculated volume of the horn.

Approximation of true volume was accomplished by calculating the volume of a sample of 58 horns and then measuring their actual volume by water displacement. True volume was found to be 54.4 percent of the calculated volume (standard deviation = 3.3 percent) and all calculated frustal volumes were, therefore, multiplied by 0.544 to derive an estimate of true volume.

For purposes of analysis, horn data were grouped according to the mountain range from which an animal was taken. Data from each mountain range were then subdivided into areas on the basis of their geologic history and similarities of physiography to allow comparisons within ranges (Fig. 2 and Appendix I). For example, the Alaska Range east of Mt. McKinley National Park (ARE) was divided into three subareas, ARE I, ARE II and ARE III. ARE I comprises the western portion of the ARE and includes the drainages of Healy Creek, Wood River, Dry Creek and the West Fork of Little Delta River. ARE II is the central portion of the ARE; it includes the Granite Mountains and drainages of the Gerstle, Little Gerstle and Johnson Rivers. ARE III is the easternmost portion of the ARE and includes drainages of the Robertson, Tok and Dry Tok Rivers. The physiography and geologic history of these three subareas differ considerably. ARE I has only a few small existing glaciers on presently occupied sheep range and portions of ARE I supporting the greatest concentration of sheep have never been glaciated (Coulter

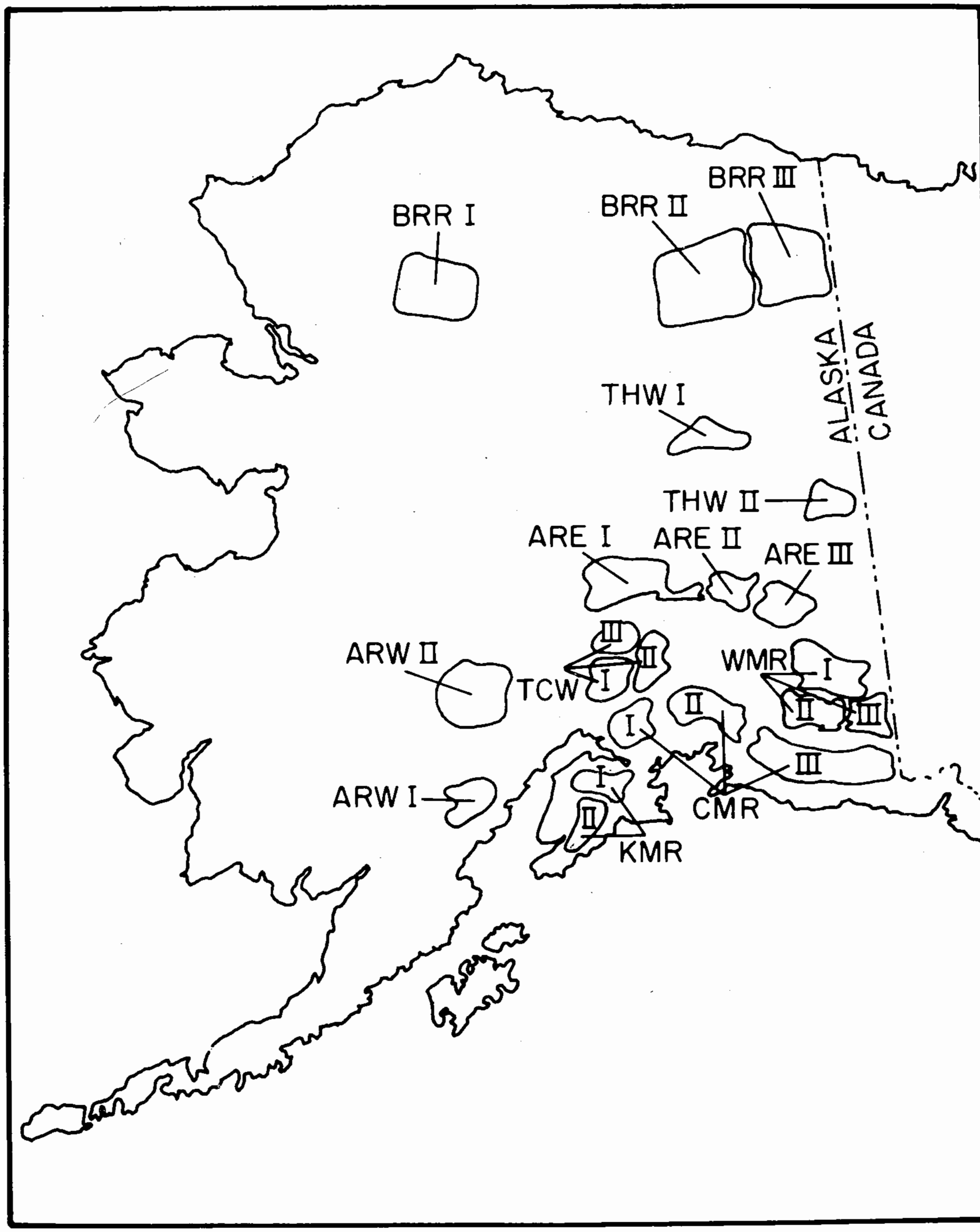


Fig. 2. Study areas within Alaska's mountain ranges.

et al., 1962). In general, ARE I consists of comparatively gentle and easily negotiable terrain compared with the remainder of the Alaska Range East. In ARE II the terrain is rugged with large persisting glaciers at the headwaters of all major drainages. ARE II was extensively glaciated during the Illinoisian glaciation with some glaciation present in the Wisconsin (Coulter et al., 1962). The eastern Alaska Range East (ARE III) is somewhat less rugged than ARE II. It has some persisting glaciers, but they are generally smaller than those of ARE II. This area was almost completely covered during the advances of Wisconsin glaciation but had little earlier glaciation (Coulter et al., 1962).

In an effort to achieve optimal sample densities for comparisons within mountain ranges some concessions were made in the subdivisions. Even with these concessions, however, some areas (BRR I, CMR III and TCW III) were inadequately represented in our sample. Consequently, no conclusions could be drawn regarding the quality of rams within them. In addition, this division of the mountain ranges into physiographic areas did not reflect the complete distribution of sheep in any mountain range. Regions between discontinuous physiographic units such as ARW I and ARW II were not assessed in this study. Subdivisions of the Brooks Range are inordinately large (Fig. 2) and conclusions regarding Brooks Range sheep are likely to be less reliable than those for sheep from mountain ranges where sampling densities were greater.

These horn growth data were then compared between and within mountain ranges on the basis of several parameters which are indicators of quality or "desirability" to the trophy hunter. Each of these parameters is also an indicator of population quality within the framework of the "Quality Hypothesis" of Geist (1971). It should be emphasized that "quality" is arbitrarily defined by these criteria and has little relationship to the usual connotation which is ascribed to the word. Parameters used were:

Mean Volume of Horns at Seven Years of Age

Seven years of age was chosen for two reasons. Rams have completed most of their horn growth by the age of seven years, and further growth would probably not change their standing in a ranking of volumes at age seven within each area of each mountain range. In addition, the average age of animals taken in some of the more heavily hunted areas precluded even moderate sample sizes if the age selected for comparison had been greater than seven years.

This statistic was calculated by determining the volume of each segment present on every horn, summing these volumes through the seventh year of growth for each ram which had reached that age or older and then dividing by the sample size to determine the mean for each area of each mountain range. No allowance was made for variance caused by broomed horns. This probably increased the variability and limited the resolving power of the statistical test used, the Student-Newman-Kuels test (Sokal and Rolf, 1969). Also for this reason, the mean seven-year volume cannot be precisely derived by summing the mean growth rates through seven years.

Mean Maximum Attainable Volume

Sample sizes from each area were limited by the ages of the sheep harvested within that area. Nevertheless, harvests from some areas contained enough mature rams, 9 to 10 years of age, to provide an indication of the ultimate size which could be expected from the area. For these areas the cumulative segment volume of each horn was plotted against the year of life. A classical "s-shaped" curve resulted. Horn growth is slow in early life, followed by a period of rapid growth, then a slowing in rate as rams reach old age.

Because many areas were not represented by a sufficient number of older rams to enable direct measurement of this statistic, a third degree polynomial equation was derived from the data for each area using biomedical data program 05R for the IBM 360 computer (Dixon, 1971). This equation, of the general form $y = ax^3 + bx^2 + cx + d$, generated the appropriate "s-shaped" curve. The resulting curve has properties which can be mathematically evaluated including the maximum value. This property is one of the extrema of the function and can be determined by evaluating the first derivative at $x=0$. If the sign of the second derivative at $x=0$ is positive, then the value is the highest achieved by the function.

An equation describing horn growth for each of the study areas was produced in this manner, and each equation was evaluated to determine the theoretical maximum volume achievable by average rams in that area. This treatment also indicated the age at which the maximum volume would be expected to occur.

Mean Maximum Sustained Growth Rate

Average segment volumes for each year of growth were determined. These volumes represent growth rates and are expressed as cm^3 of horn produced per year of life. For the three years of most rapid growth the average volume of horn produced in each segment was summed and the mean volume determined. Three years of growth were averaged rather than using only one year in an effort to minimize variation caused by limited sample sizes from some areas and to give added weight to areas which produce large horn volumes over extended periods of time.

Average Diameter of Horn Curl Measured on the 90°-270° Plane

Length of sheep horns is an important measure of trophy quality to most hunters, and it was important to consider the average lengths which might be expected in each area. Unfortunately, horn length data have the same inadequacies discussed under "Mean Maximum Attainable Volume," and for this reason we decided the diameter of the horn circle was a more desirable parameter for use in comparing horn length. All horns in the sample had grown through at least 3/4 of a curl, and their curl diameter was easily measured. This diameter does not change with further growth. Sheep in all areas are capable of growing horns which turn through a full curl or more, and the length of two horns, one of high quality and one of low quality, will be determined by their diameters of horn curl if the degrees of curl are the same (circumference = πx diameter). Consequently, diameter of horn curl provides a comparable index of attainable length.

Quality Indices

Values for each of the parameters obtained from the sample of rams representing every area were summed to obtain a quality index for each area. That is, the value for volume at seven years of age was added to the value for maximum attainable volume, the value for maximum sustained growth rate and the value for diameter of the horn curl. These sums were defined as "Quality Indices" and sheep from each area were ranked according to their quality index score. The area producing sheep with the highest quality index score was regarded as the area of highest quality, and that of the lowest quality index score the area of lowest quality.

It may be argued that this approach gives excessive weight to the mean maximum attainable volume. To assess the influence of this theoretical value on quality indices, an alternative method of determining the quality index was chosen which weighed all correlates of quality equally. The numerical value of an area's rank was determined by summing its relative position in the ranked lists for each of the four parameters. Using this system the area with the lowest alternate quality score (highest rank on each list) had the highest quality.

To minimize the danger of drawing erroneous conclusions, tests of significance were performed whenever appropriate. Statistical comparisons were made using the Student-Newman-Kuels test (Sokal and Rolf, 1969). This is a multirange test which compares means. Based on sample size, inherent variability in the sample and absolute value of the means, this test gives the probability that differences between means will be considered "real" when they are not. The accepted probability of error has been established by traditional usage at 5 percent. In instances where differences were considered biologically important but were not statistically real at the P=0.05 level, we rejected statistical conservatism in favor of biological judgment.

Results

Mean Volume at Seven Years of Age

A listing of mean volumes of ram horns at seven years of age and the standard deviations about these means for each area (Table 1) reflects differences between mountain ranges. These differences are slight and not statistically significant because of the large variations within major mountain ranges. Areas within each mountain range were compared statistically to determine if these large differences are significant. No statistically significant differences were found between areas within Alaska's mountain ranges except for the following:

Alaska Range east of Mt. McKinley: ARE I rams were significantly different from rams of ARE II and ARE III, but ARE II rams did not differ significantly from ARE III rams.

Talkeetna Mountains: TCW I rams were significantly larger than those of TCW II.

Wrangell Mountains: All groups were significantly different from each other.

There is a possibility that differences between areas were not statistically significant because the mountain ranges had been divided into study areas that were not homogeneous or the sample sizes were too small to show differences which existed. It is also possible that there actually is no difference between some units within a mountain range. Nevertheless, those ranges with which we were most familiar, and which were known to have been divided into homogeneous areas and adequately sampled, showed statistical differences in the mean horn volumes at seven years of age.

We believe that most, if not all, mountain ranges contain sheep populations in which average ram horn volume at age seven varies significantly. We also believe that differences would be proven statistically significant if the mountain ranges were properly divided into homogeneous units and the rams sampled more adequately.

Mean Maximum Attainable Volume

We must reemphasize that expected maximum volumes for ram horns from each area (Table 1) were predicted from equations describing data for a sample of sheep horns from that area. Where the sample size was large, as in ARE I (n=63), these predictions were within a few cm^3 of the actual cumulative volume at old age, demonstrating the validity of the technique. Nevertheless, in areas where the sample size was small the predicted

Table 1. Mean volume at seven years of age and computed mean maximum attainable volume by area within each mountain range.

Mt. range/area	Sample size	Mean volume at 7 yrs. cm^3	Mean maximum expected vol. cm^3
Alaska Range East			
ARE I	65	1282 ± 284	1841
ARE II	37	1549 ± 410	2153
ARE III	16	1796 ± 393	2301
Alaska Range West			
ARW I	8	1100 ± 256	1628
ARW II	14	1355 ± 373	1793
Brooks Range			
BRR I	2	1165 ± 202	–
BRR II	28	1316 ± 269	2151
BRR III	40	1272 ± 315	2071
Chugach Mountains			
CMR I	30	1215 ± 373	2042
CMR II	18	1509 ± 511	2691
CMR III	3	1624 ± 141	–
Kenai Mountains			
KMR I	10	1219 ± 252	1868
KMR II	13	1519 ± 481	2131
Talkeetna Mountains			
TCW I	8	1584 ± 573	2616
TCW II	29	1089 ± 459	2274
TCW III	3	1448 ± 283	–
Tanana Hills-White Mts.			
THW I	6	1584 ± 246	2297
THW II	6	1474 ± 318	2221
Wrangell Mountains			
WMR I	25	1332 ± 321	1809
WMR II	8	1495 ± 487	2333
WMR III	14	1921 ± 381	2503

volume may have been greatly influenced by a few unusually large or small individuals present in the sample.

Because of the close agreement between predicted and actual values where comparison was possible, and because the same treatment was applied to all data, the predicted values are considered valid for comparative purposes. We also believe they provide an acceptably accurate indication of maximum size for each area.

Mean Maximum Sustained Growth Rate

In our presentation of the mean maximum sustained growth rate data for each area (Table 2) the three years of most rapid growth are represented by the middle year of the three years averaged. Rams in nearly all areas attain their maximum sustained horn growth rates at the ages of 4, 5 and 6 years. Rams from the central Brooks Range (BRR II) are an exception, experiencing their greatest growth rates in years 5, 6 and 7. Rams in the eastern Brooks Range (BRR III), which experience maximum sustained horn growth in years 6, 7 and 8, were another exception. Equations used to predict maximum attainable volumes for these sheep indicated that these two groups would require 11 and 12 years, respectively, to reach their theoretical maximum volume. The predicted age for attainment of theoretical maximum volume was 10 years in other areas. These two factors indicate that Brooks Range rams probably have horn growth patterns which are retarted in relation to rams from other parts of Alaska.

Mean Diameter of Horn Curl Measured on the 90°-270° Plane

Data showing mean diameter of horn curl for each area (Table 2) reflect the similarities between mountain ranges. Areas within each mountain range were compared statistically to determine if differences in mean diameter of horn curl occurred between portions of a mountain range. The following are the only differences within mountain ranges which were found to be statistically significant.

Alaska Range East: Rams of ARE I were significantly smaller than rams of ARE II and ARE III, but ARE II rams did not differ significantly from those of ARE III.

Wrangell Mountains: Rams from all subareas were statistically different from each other.

When values for mean diameter of horn curl listed in Table 2 are tested statistically as a group, the only significant differences apparent are between the larger diameters (greater than 27.9 cm) and those below 26.7 cm. Intermediate values for diameter of horn curl do not differ significantly. Nevertheless, differences in this instance are of clear biological significance because a variation of 1 cm in diameter reflects a difference of about one and one-half inches in horn length of a full curl ram. An average difference of this magnitude is of definite concern to trophy hunters.

Quality Indices

Listing each area according to its rank in all four parameters provides an indication of the relative quality of sheep from each area and mountain range. However, to quantify overall quality, values of the four parameters were summed for sheep from each area to assign to each an index of quality (Table 3).

Ranked quality index scores conveniently fall into several logical groups (Table 4). The first of these is comprised only of WMR III. The second group consists of CMR II, TCW I and ARE III, areas which have quality scores which are considerably less (243

Table 2. Mean maximum sustained horn growth rate, year of maximum average growth and mean diameter of horn curl by area within each mountain range (year of maximum average growth is middle year of three years averaged).

Mt. range/area	Mean max. sustained growth rate and age of average maximum growth (cm^3/yr.)	Mean diameter of curl (cm)
Alaska Range East		
ARE I	282 @ 5 yrs.	26.7
ARE II	351 @ 5 yrs.	28.1
ARE III	402 @ 5 yrs.	29.0
Alaska Range West		
ARW I	303 @ 5 yrs.	24.3
ARW II	293 @ 5 yrs.	26.1
Brooks Range		
BRR II	295 @ 6 yrs.	27.9
BRR III	332 @ 7 yrs.	29.0
Chugach Mountains		
CMR I	330 @ 5 yrs.	26.6
CMR II	410 @ 5 yrs.	27.4
Kenai Mountains		
KMR I	322 @ 5 yrs.	26.5
KMR II	382 @ 5 yrs.	28.6
Talkeetna Mountains		
TCW I	392 @ 5 yrs.	27.0
TCW II	301 @ 5 yrs.	25.6
Tanana Hills-White Mts.		
THW I	361 @ 5 yrs.	26.7
THW II	363 @ 5 yrs.	27.8
Wrangell Mountains		
WMR I	326 @ 5 yrs.	27.1
WMR II	338 @ 5 yrs.	23.9
WMR III	426 @ 5 yrs.	30.4

Table 3. Quality index of rams by area within each mountain range.

Mt. range/area	7-year volume	Maximum expected volume	Maximum sustained growth	Diameter of curl	Quality index
Alaska Range East					
ARE I	1282	1841	282	26.7	3432
ARE II	1549	2153	351	28.1	4081
ARE III	1796	2301	402	29.0	4528
Alaska Range West					
ARW I	1100	1628	303	24.3	3055
ARW II	1355	1793	293	26.1	3467
Brooks Range					
BRR II	1316	2151	295	27.9	3790
BRR III	1272	2071	332	29.0	3704
Chugach Mountains					
CMR I	1215	2042	330	26.6	3614
CMR II	1509	2691	410	27.4	4637
Kenai Mountains					
KMR I	1219	1868	322	26.5	3436
KMR II	1519	2131	382	28.6	4061
Talkeetna Mountains					
TCW I	1566	2616	392	27.0	4601
TCW II	1089	2274	301	25.6	3690
Tanana Hills-White Mts.					
THW I	1584	2297	361	26.7	4269
THW II	1474	2221	363	27.8	4086
Wrangell Mountains					
WMR I	1332	1809	326	27.1	3494
WMR II	1495	2333	338	23.9	4190
WMR III	1921	2503	426	30.4	4880

Table 4. Areas ranked according to quality index values provided in Table 3.

Area	Rank	Quality index score	Difference from next higher index score
WMR III	1	4880	–
CMR II	2	4637	243
TCW I	3	4601	36
ARE III	4	4528	73
THW I	5	4269	259
WMR II	6	4190	79
THW II	7	4086	104
ARE II	8	4081	5
KMR II	9	4061	20
BRR II	10	3790	271
BRR III	11	3704	86
TCW II	12	3690	14
CMR I	13	3614	76
WMR I	14	3494	120
ARW II	15	3467	27
KMR I	16	3436	31
ARE I	17	3432	4
ARW I	18	3055	377

quality units) than WMR III and considerably greater (259 quality units) than the next lower group. Those in the third group (THW I, WMR II, THW II, ARE II and KMR II) have quality index scores which are much greater (271 quality units) than the highest area represented in the fourth grouping. This grouping (BRR II, BRR III, TCW II, CMR I, WMR I, ARW II, KMR I and ARE I) is again considerably higher in quality score (377 quality units) than the lowest quality area, ARW I.

Alternate Method of Determining Quality Index

Summing the numerical values of rank for rams from all areas under each parameter (Appendix II) produced an alternate index of quality (Table 5). In this case the area with sheep of the lowest total quality score (highest rank on each list) has the highest quality rating.

Comparison of Table 5 with Table 4 shows that although there are some changes in position using the alternate method of determining quality index scores, areas did not change rank significantly. This supports the validity of using "maximum attainable horn volume" as a comparative measure of general herd quality.

The similarity of quality scores for sheep from the Tanana Hills-White Mountains (THW I and THW II) in this quality ranking system also supports the general validity of this approach to quality ranking. THW I and THW II are similar in their present physiography and geological history. Neither area was ever extensively glaciated and the only difference was the former presence (glaciations of middle and late Pleistocene) of larger and more numerous (but still discontinous) glaciers in THW II (Coulter et al., 1962). Habitat in both areas consists of rather low hills which are relatively arid compared with other Dall sheep habitat and both areas contain fairly extensive coniferous forests. There is little reason to separate the areas except that they are divided by a zone of about 70 miles in which sheep are absent. Tables 4 and 5 show that rams from both areas consistently fall within the same general quality grouping and are separated by only one other sample group regardless of the quality ranking system utilized. Because there is little difference in the habitat supporting these populations, and little known difference between the populations themselves, the failure of the quality ranking systems to separate them further is supportive of this concept of quality ranking.

Discussion

Differences in Dall sheep quality reflected by ram horn growth patterns doubtless are attributable to factors such as range quality or genetics. Unfortunately, however, data of sufficient scope and breadth to allow cause and effect evaluation of these direct factors are not presently available. Consequently, our discussion must be limited to indirect and perhaps more fundamental considerations.

The writings of Geist (1971) provide one possible explanation for quality differences found in this study. Geist proposed a system of thought based on morphology and behavior which he termed the "Dispersal Theory." This hypothesis states, in part, that:

> Mountain sheep evolved during postglacial dispersal into uninhabited favorable terrain. They specialized increasingly toward delivering a more forceful clash and changed by growing relatively heavier horns, larger rump patches, acquiring more pneumation in the skull, increasing the length of the horn cores, shortening and rounding the ears, and losing the cheek and neck manes.

Table 5. Alternate method of determining quality index of Dall rams in Alaska based on summed rankings for each parameter.

Area	Rank in 7 yr. volume array	Rank in max. expected volume array	Rank in growth rate array	Rank in diameter of curl array	Total quality score
WMR III	1	3	1	1	6
ARE III	2	5	3	2	12
CMR II	7	1	2	8	18
TWC I	4	2	4	10	20
KMR II	6	11	5	4	26
ARE II	5	9	8	5	27
THW I	3	6	7	12	28
THW II	9	8	6	7	30
WMR II	8	4	9	18	39
BRR III	14	12	10	3	39
BRR II	12	10	15	6	43
WMR I	11	16	12	9	48
CMR I	16	13	11	13	53
TCW II	18	7	14	16	55
KMR I	15	14	13	14	56
ARE I	13	15	18	11	57
ARW II	10	17	16	15	58
ARW I	17	18	17	17	69

If this hypothesis, which was formulated for a geological time frame, remains valid, it seems logical that mountain sheep living in areas which are extensively glaciated at present should have larger horns than those living in areas of less glaciation. Likewise, since our definition of quality is based almost entirely on horn size, it also should follow that Dall sheep presently occupying areas of extensive glaciation would be of higher quality than those of presently unglaciated areas.

In order to assess the relationship between present glacial cover and Dall ram quality, subunits of each mountain range were outlined on USGS topographic maps (scale 1:250,000) and the area of each unit was measured with a compensating polar planimeter. Areas shown to be covered by glaciers were then outlined and measured in the same manner and percent glacial cover was calculated (Table 6).

Quality index scores were then plotted as a function of glacial cover (Fig. 3). Statistical tests performed on these data indicated a weak correlation coefficient of 0.41.

This lack of a strong correlation between percent glacial cover and quality score may be the result of the following: (1) errors were made in determining glacial cover, (2) the quality index is not valid or (3) little real relationship exists between quality in Dall rams and present glaciation. It is unlikely that errors of significant magnitude were made in determining percent glacial cover since the procedure used was the same for all units examined. We have already demonstrated that parameters used to determine quality index were internally consistent, and using the alternative method for evaluating quality index only increased the correlation coefficient to 0.47.

When significance probabilities are assigned to the correlation coefficient as outlined in Simpson et al. (1960), a correlation coefficient of this magnitude is significant at the P=0.10 level. This means there is at least a 10 percent chance of erroneously stating that the "Dispersal Theory" correctly predicts the quality of Dall rams in any given area. Most biological works reject a conclusive statement at this probability level. The indication here is that quality is generally higher in glaciated areas although factors other than glacial cover may be of greater importance. Population density was postulated to be one such factor.

To test this possibility it was necessary to know the number of Dall sheep inhabiting each subarea; the area of each was already available from the preceding test. Accurate total population figures for Dall sheep will probably never be available; nevertheless, systematic aerial surveys have been made in the Alaska Range, the Kenai Mountains, Talkeetna Mountains, Tanana Hills-White Mountains and Wrangell Mountains. These surveys provided acceptable minimum estimates of sheep numbers from which to compute densities (Table 6). It is improbable, even under the best conditions, that all Dall sheep inhabiting these areas were observed, but for reasons of consistency the highest number of animals seen on any given survey area was used as the index of total population numbers.

When the same analytical procedures as described for glacial cover were applied to quality as a function of population density (Fig. 4), the correlation coefficient was found to be -0.74. This is considered a strong correlation coefficient for biological work and the level of significance in this case was found to be P=0.01 (Simpson et al., 1960). This suggests that there is 1 chance in 100 of being incorrect in concluding that the density of sheep on the range may determine the quality of rams in the population.

If data for population quality as a function of population density are plotted and lines are drawn connecting the subunits of each mountain range, several interesting aspects of the effects of population density on Dall ram quality emerge (Fig. 5). In all mountain

Table 6. Percent glacial cover, population density and Dall ram quality by area within each mountain range.

Mountain range/ area	Total area (mi^2)	Glacial area (mi^2)	Glacial percent	Total sheep population (observed)	Density (sheep/ mi^2)	Quality score
Alaska Range East						
ARE I	1911.5	343.4	18.0	4142	2.17	3432
ARE II	769.2	175.0	22.7	1103	1.43	4081
ARE III	1237.0	110.5	9.0	1140	0.92	4528
Alaska Range West						
ARW I	352.1	48.2	13.7	—	—	3055
ARW II	1602.1	43.2	2.7	—	—	3467
Chugach Mountains						
CMR I	945.0	98.1	10.4	—	—	3614
CMR II	1726.7	413.3	23.9	—	—	4637
Kenai Mountains						
KMR I	538.8	13.2	2.4	1203	2.23	3436
KMR II	762.0	16.4	33.7	992	1.37	4061
Talkeetna Mountains						
TCW I	1730.7	165.1	9.5	423	0.24	4601
TCW II	1268.8	15.8	1.2	1759	1.39	3690
Tanana Hills-White Mts.						
THW I	1419.1	0.0	0.0	286	0.20	4269
THW II	534.0	0.0	0.0	285	0.53	4086
Wrangell Mountains						
WMR I	3526.0	390.2	11.1	6069	1.71	3494
WMR II	1806.3	367.7	20.3	1060	0.59	4190
WMR III	1502.9	731.2	48.7	1202	0.79	4880

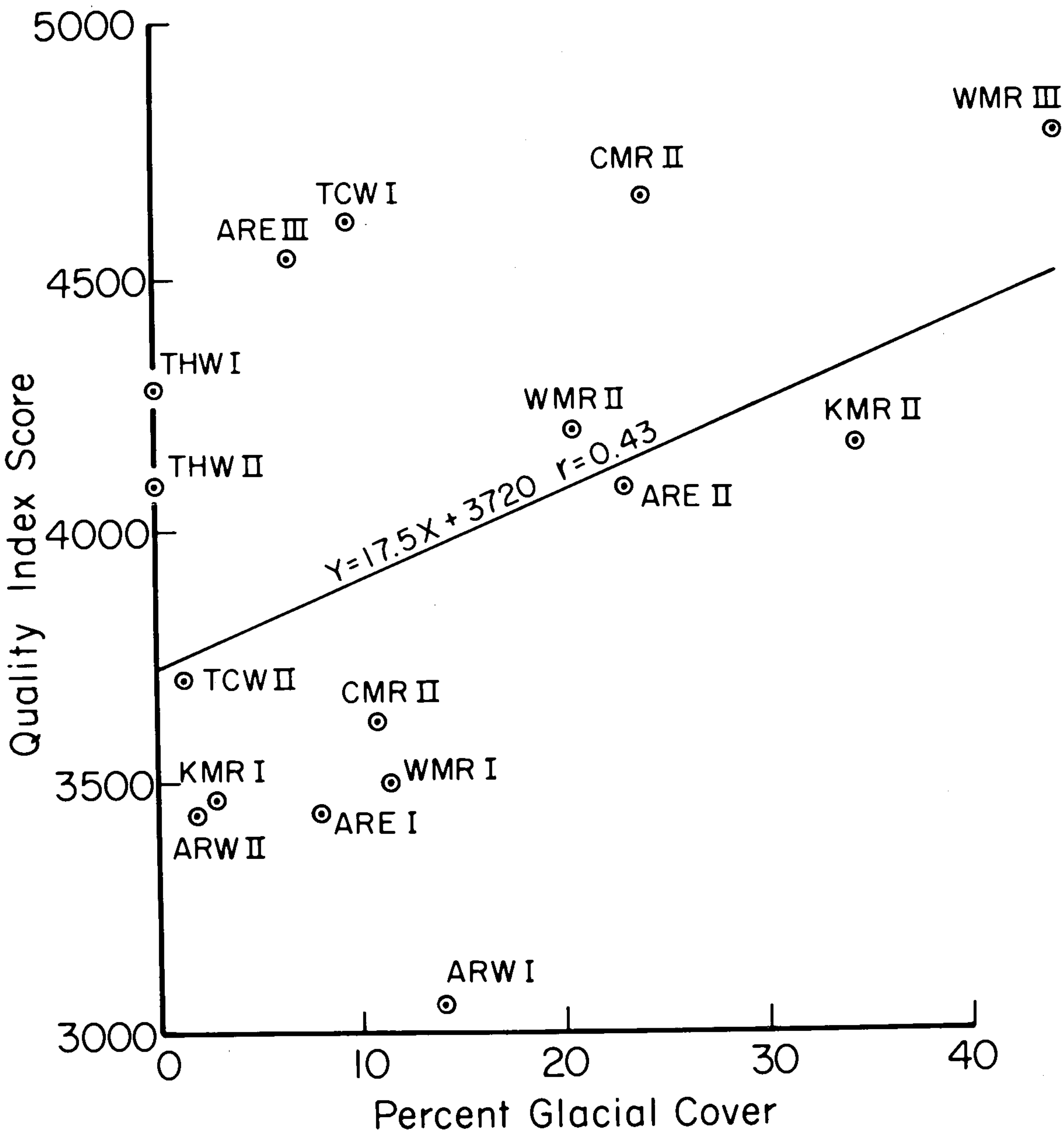


Fig. 3. Quality index of sheep as a function of percent glacial cover in sample areas.

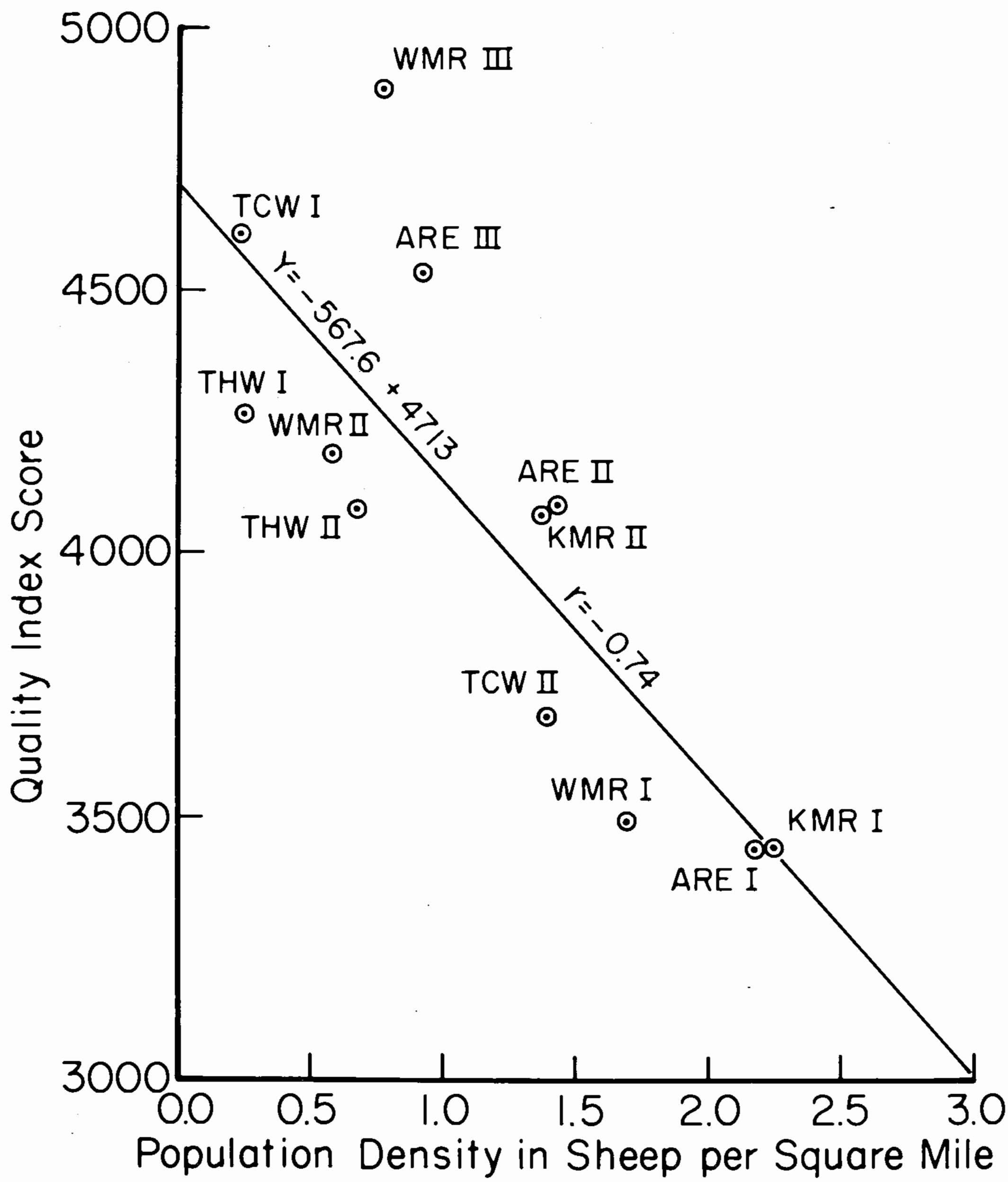


Fig. 4. *Quality index of sheep as a function of sheep population density in sample areas.*

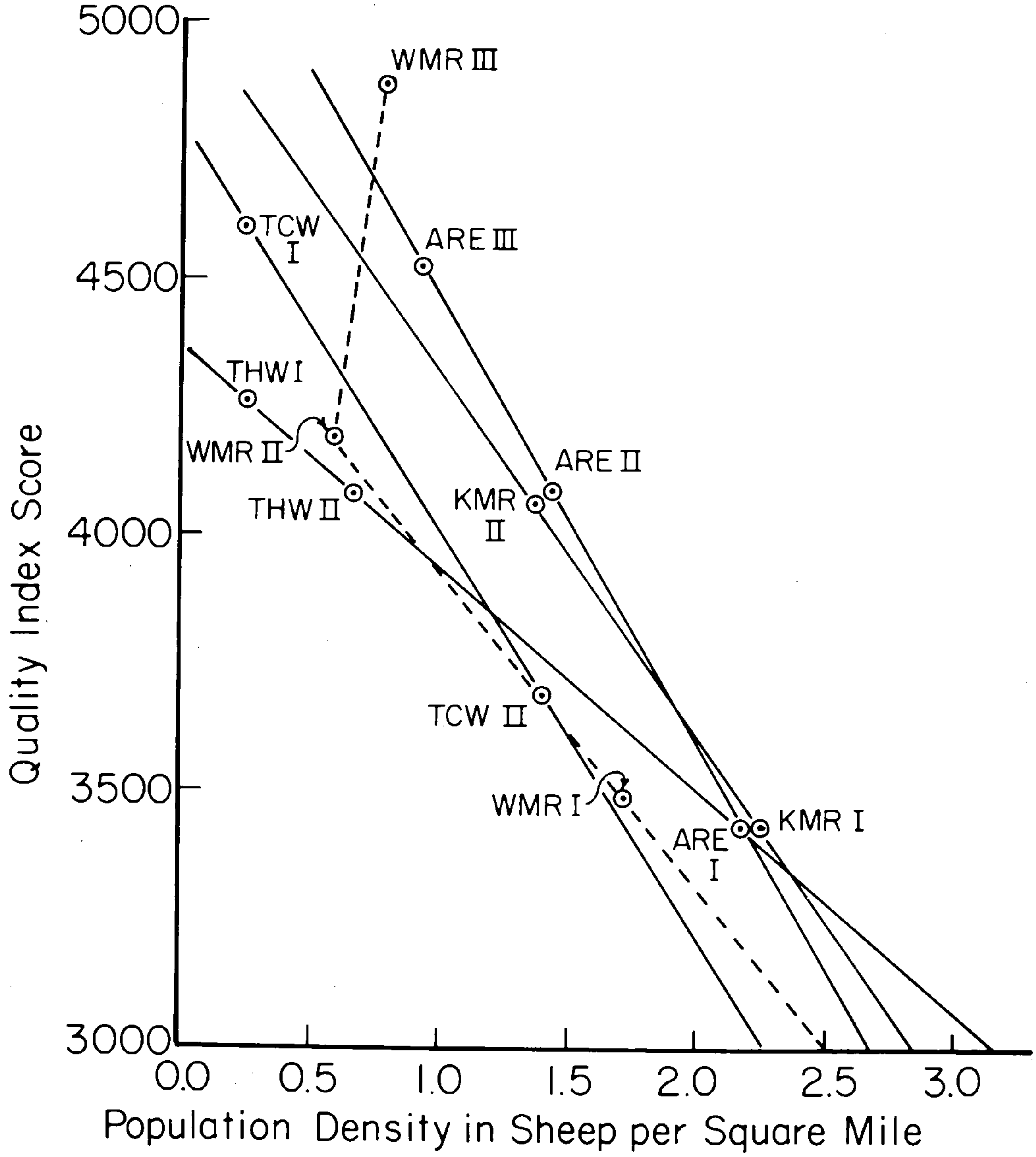


Fig. 5. Relationship of quality and population density within each mountain range.

ranges where there are acceptable sheep population estimates, the relationship between number of animals per unit area and quality is linear except for the Wrangell Mountains. Fig. 5 shows that WMR III, the southeast corner of the Wrangell Mountains, has a quality score which, in light of comparative data from other areas, is high for the density of Dall sheep present there. This indicates that WMR III is the highest quality sheep habitat in Alaska, and is probably atypical. It appears that WMR II and WMR III are unique in Alaska because they are the only Dall sheep ranges subjected to the maritime influences of the Gulf of Alaska which are both on the south side of a mountain range and may be in the "snow shadow" of another mountain range (Appendix III). WMR III is presently extensively glaciated but has snow fields which are quite small compared to WMR II to its west. The vast ice fields of WMR II are probably produced by high precipitation from moist air which makes its way from the Gulf of Alaska up the Copper River Valley and across Thompson Pass to be deposited on Mt. Wrangell (14,163'), Mt. Zanetti (13,009'), Mt. Sanford (13,237'), Mt. Jarvis (13,421') and the ice fields of the Nabesna Glacier (7,000'-9,000'). Precipitation which could fall on WMR III is probably deposited mainly on the Bagley Ice Field (4,000'-5,000') of the eastern Chugach Mountains.

Cold temperatures, moderate snowfall and persistent winds are important components of favorable winter habitat for Dall sheep (ADF&G, 1973). These factors result in a ready availability of winter forage to the animals. In WMR III these conditions prevail (as indicated by the high quality population and relatively high density of animals on the range) and the southern exposure of slopes to the winter sun apparently results in very favorable wintering conditions.

Information in Fig. 5 also suggests that by lowering the density of sheep in any given area it may be possible to increase quality. Here it is tempting to infer that density regulates quality through a nutritional mechanism. Data on nutrition of Dall sheep are scant and only further study will reveal whether, for certain, quality can be altered by changing sheep density on the range.

Theoretically, extension of the lines for the mountain ranges in Fig. 5 to their points of intersection with the abscissa would provide a prediction of the maximum density of animals supportable in each mountain range. This corresponds to a quality value of about 3,000 which we suspect represents the lowest extreme of quality in Dall rams.

Quality scores of rams from ARW I were 3,055, the lowest recorded. This is an area of 13.7 percent glacial cover, and limited population data indicate low sheep densities. Low quality scores in spite of apparent low sheep density may be the result of marginal habitat which is on the western limits of the species' range (Fig. 2). In addition, ARW I is susceptible to the influences of Bristol Bay, and may receive more precipitation and warm winter weather than is suitable for high populations of Dall sheep. If environmental conditions there are indeed marginal, the animals present would be expected to be of the lowest possible quality. It should be noted here that there is a general trend toward greater predicted sustainable densities in mountain ranges of lesser expected precipitation.

Fig. 5 indicates that the mountain range with the greatest potential for sustaining high densities of sheep is the Tanana Hills-White Mountains. This area is well screened from all maritime influence and has the least snowfall of all Dall sheep ranges in Alaska (Appendix II).

The Kenai Mountains have the second greatest predicted capability for supporting high concentrations of Dall sheep. Although the Kenai Mountains appear to have fairly heavy snowfall (Appendix III), snowfall patterns reveal that sheep habitat on the Kenai Peninsula is in a snow shadow. KMR I is especially sheltered and has the highest density of sheep of any area sampled. The Alaska Range East falls just below the Kenai Mountains in predicted sustainable sheep density. All known Dall sheep in this mountain range occupy the north side of the mountains where precipitation is less than on the south side.

In the Talkeetna Mountains, the southwest portion (TCW I) has the greatest snowfall and the lowest sheep density while TCW II, which is in the snow shadow of the Chugach Mountains, has a fairly high density of sheep. The Wrangell Mountains may be atypical in this comparison. WMR I and WMR II conform to the established pattern with WMR I having high population density and low snowfall. WMR II has low sheep density and high snowfall. As discussed previously, WMR III is the notable exception.

It appears that the areas where sheep quality is least influenced by population density are those which are sheltered from precipitation and maritime influence. These areas may support greater population densities of Dall sheep without attendant decreases in quality.

Summary

1. Quality differences exist among Dall sheep populations with respect to ram horns where quality is defined in terms of horn volume at a comparable age, maximal attainable horn volume, maximum sustained growth rate and diameter of horn curl.

2. Generally speaking, quality in Dall rams is inversely related to population density.

3. Physiography, glacial history and present glaciation appear to influence quality to an extent which, although unknown, is less than that exerted by population density.

4. Climate appears to regulate sheep population density and is probably the ultimate determinant of sheep quality through mechanisms which are not yet understood.

MANAGEMENT CONSIDERATIONS

Methods and Materials

Horn lengths at 3/4 and full curl were calculated for rams in each area of Alaska by assuming that each Dall ram horn was a perfect spiral which described a right, circular cylinder (Fig. 6). If a cylinder described by a full curl horn were unrolled, the horn would be theoretically unrolled and the base of the right triangle formed (Fig. 6) would be equal to the diameter of the horn coil multiplied by π. The height of the triangle would be equal to the pitch of the spiral (mm of divergence from the midline of the skull to the horn tip per revolution) multiplied by the number of revolutions, in this case either 1.0 for a full curl or 0.75 for a 3/4 curl. The hypotenuse of the triangle (calculated by the theorum of Pythagoras) equals the length of the orbital surface of the horn from its base to tip.

Once these standard (3/4 curl and full curl) lengths had been determined, the yearly segment lengths of horns from each area were cumulatively added until the lengths for 3/4 and full curl were reached. Because the cumulative segment lengths did not always match exactly the standard lengths, the year in which the ram horn was closest to the standard length was used to calculate the mean age at 3/4 curl and full curl for rams of each study area.

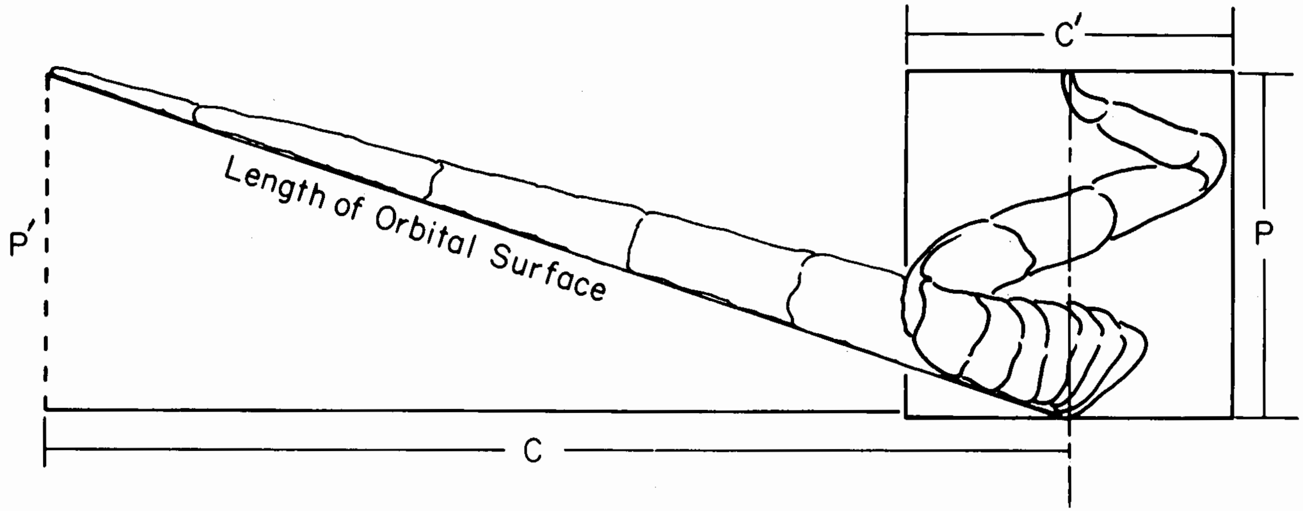
A year's growth was considered to be from one annulus to the next, i.e., from December to December. Rams taken during the hunting season (August and September) would have produced their terminal horn segments between December and the time of their death, but would not yet have formed annuli. When ram horns were not at least one year's growth greater than 3/4 or full curl, the ages were rounded off to the next higher year because approximately three-fourths (9 months) of the potential growth time had elapsed. Thus, rams were considered to have utilized the entire yearly growth season even though they were killed 2.5 to 3 months before annulus formation. Using this system, the number of annuli equals the number of complete horn growth years.

Once lengths and ages of 3/4 curl and full curl ram horns were known, it became possible to calculate their volumes for rams of each study area. The basal diameters of 3/4 curl and full curl horns were determined from the measurement data available for each horn. Horn volumes were calculated as previously except that the formula for the entire cone,

$$V = \frac{h}{3} r^2,$$

was used. Here "h" is the horn length, "r" is the radius of the base and "V" is volume of the entire horn. For this procedure a correction factor relating entire horn volume to calculated volume was derived by calculating volumes for 25 horns and then determining their volume by water displacement. For the entire horn the correction factor was 0.717. This correction factor was then multiplied by the calculated volume to estimate actual volume.

Statewide harvest and numbers of hunters were determined from sheep harvest ticket returns.



c' = diameter of horn curl

C = circumference of horn projected onto a plane = π X diameter

p = horn pitch = $\frac{\text{full curl spread}}{2}$

p' = p X number of revolutions (1.0 for full curl or 0.75 for 3/4 curl)

Length of orbital surface = $\sqrt{p'^2 + C^2}$

Fig. 6. Explanation of parameters used to calculate lengths of 3/4 and full curl ram horns.

Results

Rams generally achieve nearly 60 percent of maximum expected volume at 3/4 curl and slightly in excess of 90 percent of expected volume at full curl (Table 7). Maximum expected volumes are estimates; in the discussion of Dall ram quality they were used for comparative purposes only. We have departed from this rule here to determine a ram's average potential growth obtained at the age of legal harvest. These maximum values are derived and not measured. The unreasonably high percentages of expected maximal attainment at full curl observed for WMR I, BRR II, ARE II and ARE I may be due to: (1) exceptional growth patterns; (2) errors in determination of the expected theoretical maximum or (3) the differences inherent in calculating horn volumes by different methods. It is unlikely that the differences are attributable to unusual growth patterns.

Discussion

For the last 25 years, sheep hunting in Alaska has been regulated by the "3/4 curl rule" allowing only the harvest of rams with horns greater than or equal to 3/4 of a curl. In recent years, however, there have been many requests to change to a "full curl rule." These proposals are generally justified on the basis that taking a full curl ram is more satisfying than taking a 3/4 curl ram. Objections to this line of thinking are: (1) a full curl regulation would unnecessarily result in fewer harvestable rams and a lower success ratio; (2) there is little biological justification for going to a full curl regulation and (3) sheep hunters are not required to take sheep of less than their personal standards, whatever they happen to be.

The harvest of Dall rams in Alaska averaged a little over 1,000 animals per year for the last 8 years (1967-1974), and during this time the number of hunters has averaged about 3,000 (Appendix IV). Because neither the number of hunters nor the harvest has changed significantly since 1967 under the 3/4 curl regulation, there is little reason to anticipate that the statewide harvest will decrease in the immediate future. That is, it may be expected that the annual harvest will continue to be about 1,000 rams or more under 3/4 curl regulations currently in effect.

The impact of harvesting only full curl rams can be estimated using data on average ages at which rams attain 3/4 and full curl in each mountain range and area (Appendix V) and data reflecting average ages of sheep actually harvested in each mountain range (Appendix VI). If the determined average age of sheep harvested (Appendix VI) adequately reflects the age of sheep taken by hunters, it becomes apparent that in the Alaska Range East, Kenai Mountains and Talkeetna Mountains the average ram taken during 1974 was nearly two years younger than the age at which it would have attained full curl (Table 8). In the other mountain ranges (except Alaska Range West) hunters are taking animals which average about one year younger than full curl. It is evident, therefore, that imposition of a full curl regulation would result in a substantial reduction in Alaska's ram harvest.

The projected magnitude of this theoretical reduction in harvest under a statewide full curl regulation can be computed using the following information: (1) the percentage of harvested rams which had not reached the age of full curl by mountain range in our sample during 1972-1974 (Table 9) and (2) total numbers of rams taken in each mountain range during this 3-year period (Table 10). The mean harvest for these years (Table 10) minus the portion of the harvest which was less than full curl (Table 9) equals the theoretical harvest under a full curl regulation (Table 11).

Table 7. Average calculated lengths, average volumes and percentages of maximum attainable volumes of 3/4 and full curl ram horns by area within each mountain range.

Mt. range/area	Average length at full curl mm	Average length at full curl inches	Average length at 3/4 curl mm	Average length at 3/4 curl inches	Max. vol. in cc.	3/4 curl vol. in cc.	% of max.	Full curl vol. in cc.	% of max.
Alaska Range East									
ARE I	897	35.3	673	26.5	1841	1171	63.6	1855	100.8
ARE II	940	37.0	725	28.5	2153	1438	66.8	2170	100.8
ARE III	956	37.6	716	28.2	2301	1412	61.4	2161	93.6
Alaska Range West									
ARW I	821	32.3	617	24.3	1628	935	57.4	1585	97.4
ARW II	869	34.2	652	25.7	1793	1128	62.9	1807	100.8
Brooks Range									
BRR II	936	36.8	702	27.6	2151	1369	63.6	2179	101.3
BRR III	937	36.9	703	27.7	2071	1247	60.2	1775	85.7
Chugach Mountains									
CMR I	885	34.8	662	26.1	2092	1215	59.5	1979	96.9
CMR II	912	35.9	686	27.0	2691	1343	49.9	2344	87.1
Kenai Mountains									
KMR I	874	34.4	656	25.8	1868	1201	64.3	1795	96.1
KMR II	938	36.9	704	27.7	2131	1416	66.5	2084	97.8
Talkeetna Mountains									
TCW I	904	35.6	678	26.7	2616	1303	49.8	2134	81.6
TCW II	871	34.3	653	25.7	2274	1095	48.2	1999	87.9
Tanana Hills-White Mts.									
THW I	879	34.6	659	26.0	2297	1198	52.2	2077	90.4
THW II	913	35.9	685	27.0	2221	1373	61.8	2099	94.5
Wrangell Mountains									
WMR I	908	35.8	682	26.8	1809	1192	65.9	1954	108.2
WMR II	804	31.7	604	23.8	2333	936	40.2	1726	74.0
WMR III	983	38.7	737	29.0	2503	1497	59.8	2406	96.1

Table 8. Average ages at 3/4 and full curl and average age of rams harvested in 1974 by mountain range.

Mountain range	Age at 3/4 curl (yrs.)	Age at full curl (yrs.)	Average age in 1974 harvest
Alaska Range East	5.5	8.6	6.8
Alaska Range West	5.4	8.1	9.3
Brooks Range	6.7	9.7	8.9
Chugach Mountains	5.1	7.9	6.6
Kenai Mountains	5.2	7.9	6.1
Talkeetna Mountains	5.3	7.8	5.5
Tanana Hills-White Mtns.	5.7	8.8	-
Wrangell Mountains	4.9	7.3	6.6

Table 9. Numbers and ages of Dall rams in subsamples of the harvest from 1972-1974 by mountain range and the percentage of these rams which had not attained full curl.

Age in years	ARE	ARW	BRR	CMR	KMR	TCW	WMR
4	19	4	2	7	6	9	19
5	23	3	9	19	12	15	30
6	24	10	16	12	14	7	33
7	21	5	20	9*	5*	6*	31*
8	19*	8*	26	8	4	3	29
9	19	5	42*	3	-	1	13
10	13	8	41	3	-	1	12
11	5	8	26	2	-	1	5
12	4	1	13	-	-	-	2
13	1	1	7	2	-	-	-
14	1	-	5	-	-	-	-
% less than full curl	71	57	56	72	90	86	65

*age at full curl.

Table 10. Actual numbers of rams killed by mountain range during 1972, 1973 and 1974 and mean statewide harvest during this period.

Year	Mountain Range						
	ARE	ARW	BRR	CMR	KMR	TCW	WMR
1972	241	69	236	112	36	80	349
1973	187	119	242	81	59	61	363
1974	194	119	236	137	73	114	352
Mean	207	102	238	110	56	85	355

Mean total rams = 1,153

Table 11. Theoretical harvest by mountain range under full curl regulation.

	Mountain Range						
	ARE	ARW	BRR	CMR	KMR	TCW	WMR
Mean harvest	207	102	238	110	56	85	355
Percent decrease under full curl regulation	71	57	56	72	90	86	65
Expected harvest reduction under full curl regulation	147	58	133	79	50	73	231
Expected harvest under full curl regulation	60	44	105	31	6	12	124

Total rams = 382

It can be seen that the immediate result of implementing a statewide full curl regulation (all other factors remaining equal) would be a 67 percent reduction in the harvest (a decrease from an expected harvest of 1,153 rams to 382 rams). If the number of hunters (average 2,945 during 1972-74), hunter effort and distribution of hunting activity were similar to those of the last three years (1972-74), implementation of a full curl regulation would result in a decrease in hunter success from 39 percent to 13 percent. Because the sheep horns used for this study were obtained in taxidermy shops, there may have been a bias favoring older animals. If this were the case, the reduction in hunter success and harvest would be even greater than that suggested here.

Long-term reductions in harvest and success may not be as severe as those immediately following implementation of a full curl regulation. Likely, many of the animals harvested before they reached full curl under the present 3/4 curl regulation would be available for harvest as full curl rams. In most mountain ranges it takes 2.5 to 3 years for a 3/4 curl ram to reach full curl status (Appendix V). The extent of natural mortality during these years is unknown, but Geist (1971) and Murphy (1974) have suggested that attainment of dominance status and attendant energy expenditures in rutting increase natural mortality significantly during this period of a ram's life. Determination of natural mortality rates in rams between the ages of 3/4 curl and full curl will require additional field study.

Despite the paucity of knowledge regarding total sheep populations and natural mortality rates in adult rams, it is possible to roughly compute the theoretical sustainable harvest of full curl rams in Alaska. Numbers of Dall sheep observed on systematic surveys of several mountain ranges in Alaska were presented previously (Table 6). Although minimum numbers of sheep in the remaining mountain ranges are not known, conservative estimates based on available data are as follows: Chugach Mountains, 3,000 sheep; Alaska Range West, 2,000 sheep and Brooks Range, 15,000 sheep.

During systematic surveys such as those which provided the data for Table 6, biologists have often classified rams according to relative horn size. Results of these surveys indicate that the proportion of rams 3/4 curl or greater ranges from 5.7 percent in the heavily hunted ARE I to 19.9 percent on Sheep Mountain which is not hunted (Table 12). Because most areas surveyed have supported hunting under 3/4 curl regulations for an extended period of time and because in unhunted areas (McKinley Park and Sheep Mountain) the proportion of legal (3/4 curl) rams averages 15 percent, we shall assume that if Alaska were unhunted 15 percent of the population estimated earlier would be legal rams (3/4 curl or greater). That is, there would be 15 percent of about 40,000 sheep or 6,000 legal, 3/4 curl rams.

As indicated previously, virtually nothing is known about the natural mortality of rams after they reach 3/4 curl. Data published by Murie (1944) suggest, however, that 12 years is the maximum average age for Dall rams in McKinley Park. Only 2 percent of the rams in our sample were older than 12 years indicating that Murie's estimate of the maximum age of Dall rams was reliable. It takes more than 5 years (5.4 years) for the average ram in Alaska to reach 3/4 curl and if we assume that all rams will die by age 12 it follows that any ram which dies of old age will have lived 6 years after having attained 3/4 curl status.

By taking the 6,000 3/4 curl rams (ages 6 through 12) calculated to exist in a theoretically unhunted Alaska and assuming survivorship between those ages is linear, the number of full curl rams entering the population can be estimated by constructing a triangle with a base distance representing 6 years, an area of 6,000 units (representing 6,000 rams) and a calculated height which should approximate the number of rams entering the

Table 12. Percent of rams 3/4 curl and larger observed in systematic surveys.

Mt. range/area	Survey year(s)	Sample size	% ≥3/4
Alaska Range East			
ARE I	1970-73	5103	5.7
ARE II	1974	550	16.7
ARE III	1974	742	14.2
McKinley Park	1973	298	11.1
Brooks Range			
BRR II	1974	1741	12.6
BRR III	1973	1125	12.9
Talkeetna Mountains			
TCW I and II	1974	1981	8.2
Sheep Mountain closed area	1974	201	19.9
Wrangell Mountains			
WMR I, II and III	1973	8331	10.1

population at any age from 5 to 12 years (Fig. 7). Estimated recruitment to a population of about 40,000 sheep would be 2,000 3/4 curl rams per year or 1,150 full curl rams per year.

This estimate is considered to be conservative for several reasons. First, total sheep population figures were derived from numbers actually observed during systematic surveys in four of Alaska's seven mountain ranges and conservative estimates of numbers for Chugach Mountains, Brooks Range and Alaska Range West populations. In addition, our estimate that rams with 3/4 curl or larger horns comprise only 15 percent of this hypothetical unhunted population is probably conservative as well. The two unhunted populations providing the basis for this figure (McKinley Park and Sheep Mountain) are of low or average quality. In fact, the proportion of 3/4 curl rams in McKinley Park, which is unhunted, is lower than that observed in many hunted areas. Finally, use of a linear survivorship curve appears justified for full curl rams (Deevey, 1947) but the curve from 3/4 curl to death is surely not linear. Instead, it is an exponential function which, if used in our model, would predict greater numbers of full curl rams than the linear model we used. Consequently, it appears that Alaska could support a sustainable harvest of greater than 1,150 full curl rams. We must emphasize here that this theoretical level of harvest could be sustained only with a perfectly homogeneous distribution of hunters. Obviously, this is not the case at present because large areas of the Brooks Range, in particular, are not hunted.

It was shown earlier in this paper that rams of most sheep populations in Alaska can be expected to attain nearly 60 percent of their expected maximum horn volume when they reach 3/4 curl (Table 7). This figure is about 90 percent for full curl rams. The time required to produce 3/4 curl and full curl horns varies from one mountain range and area to another (Appendix VI). In an effort to explain this variation, we assessed the relationship between the time spent to attain 3/4 and full curl and quality and the relationship between this time factor and the diameter of horn curl.

Quality index scores showed no significant correlation with any of the time intervals tested (Table 13). The correlation coefficient for time to reach 3/4 curl as a function of diameter of horn curl was strong enough to be assigned a low significance probability ($P=0.10$), however. This indicates that longer times required to reach 3/4 curl for rams with larger diameter horn curl may be a result of large curl diameter or a function of other factors characteristic of each area. It appears, therefore, that the larger the diameter of curl for any given horn, the longer it will take to grow to 3/4 curl and subsequently to full curl. This is an important consideration in establishing trophy management areas in Alaska. For example, a cursory glance at Appendix VI indicates that the Tok Management Area (ARE III) is a poor choice for regulation by a "full curl" rule. Regardless, part of the time required for rams to attain full curl results from the large diameters of the horns involved. In terms of horn volume a full curl ram from ARE III will be much larger than a full curl ram from most other areas. It is important in planning to consider all aspects of quality as well as the temporal considerations of trophy production in order to determine proper areas for trophy management designation.

Summary

1. Most Dall rams in Alaska reach 3/4 curl at about six years of age. Notable exceptions occur in the Wrangell Mountains and Brooks Range. WMR II and WMR III rams reach 3/4 curl in about five years. Rams from the Brooks Range generally require seven years to reach 3/4 curl.

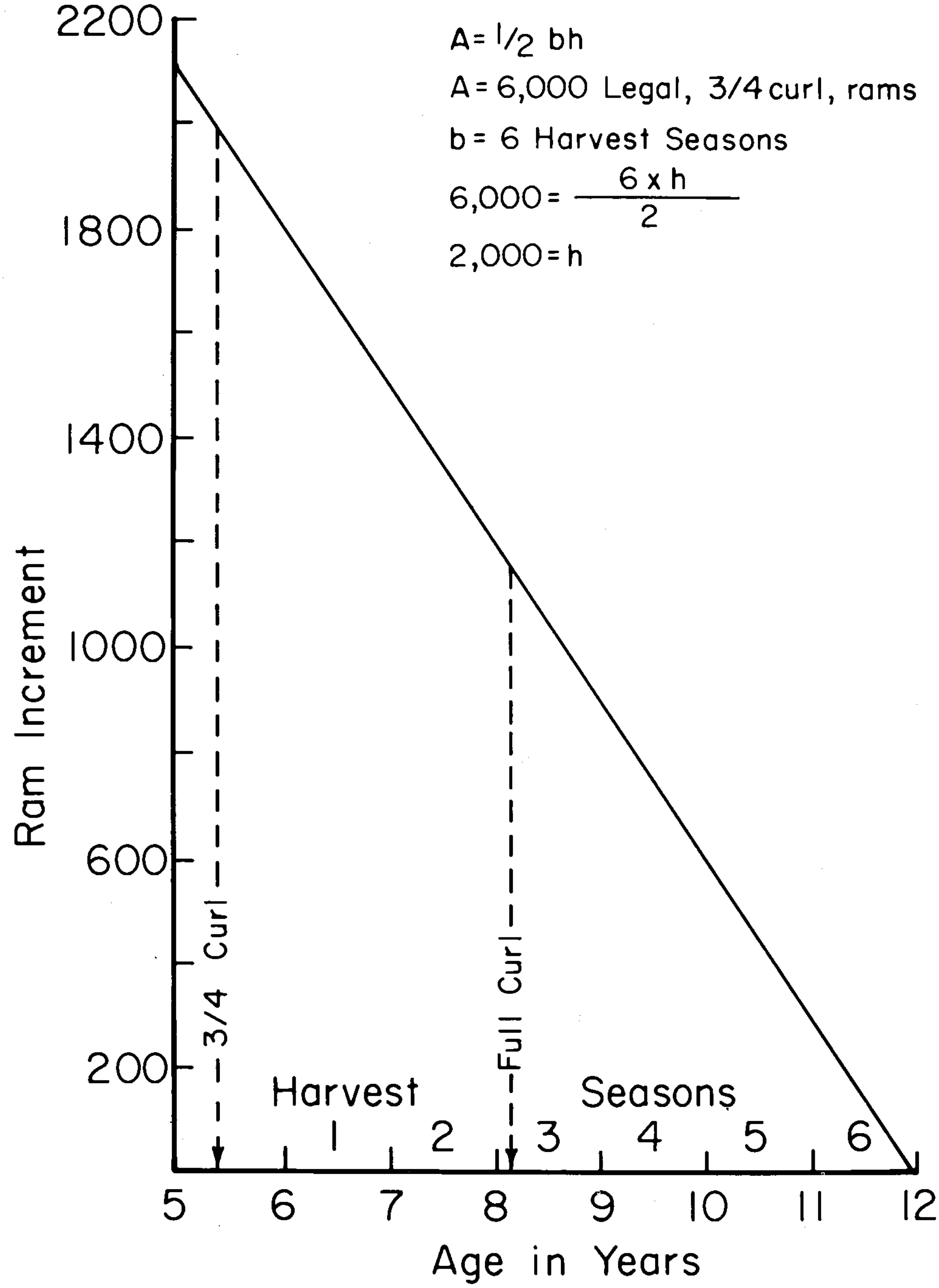


Fig. 7. *Calculation of Alaska's 3/4 curl and full curl ram increment assuming 15 percent of Alaska's sheep are 3/4 curl or greater.*

Table 13. Relationships between times to attain 3/4 curl and full curl and quality scores and mean diameters of horn curl by mountain range and subarea.

Area	Time to attain 3/4 curl (years)	Time to attain 4/4 curl (years)	Time from 3/4 to full curl (years)	Quality score	Diameter horn curl (cm)
WMR III	4.9	7.0	2.1	4880	30.4
CMR II	4.8	7.3	2.5	4637	27.4
TCW I	5.3	7.5	2.2	4601	27.0
ARE III	5.1	8.5	3.4	4528	27.0
THW I	5.5	8.0	2.5	4269	26.7
WMR II	4.3	6.8	2.5	4190	23.9
THW II	5.8	10.5	4.7	4086	27.8
ARE II	5.6	8.7	3.1	4081	28.1
KMR II	5.5	8.3	2.8	4061	28.6
BRR II	6.8	10.0	3.2	3790	27.9
BRR III	6.5	9.3	2.8	3704	29.0
TCW II	5.2	8.0	2.8	3690	25.6
CMR I	5.4	8.5	3.1	3614	26.6
WMR I	5.4	8.0	2.6	3494	27.1
ARW II	5.6	8.6	3.0	3467	26.2
KMR I	4.8	7.5	2.7	3436	26.5
ARE I	5.9	8.7	2.8	3432	26.7
ARW I	5.1	7.6	2.5	3055	24.2

Correlation coefficients for time and horn curl diameter vs. quality score.

Time as a function of:	Quality score	Diameter horn curl
3/4 curl time	r = -0.27	r = 0.40
Full curl time	r = -0.24	r = 0.29
Time from 3/4 to full curl	r = 0.12	r = 0.08

2. Rams of 3/4 curl status have varying lengths of horn, but usually have achieved about 60 percent of their total expected horn volume.

3. Most Alaskan Dall rams reach full curl at the age of about eight or nine years, but those in the Brooks Range require about 10 years to reach full curl status. Rams in two areas (WMR II and CMR II) reach full curl at about seven years of age.

4. The average full curl ram has achieved about 90 percent of his total expected horn volume.

5. The immediate results of establishing a statewide full curl regulation would be decreased harvests and hunter success. Lowered harvests and success ratios could be expected to persist for a period of time equal to that required for average rams to grow from 3/4 to full curl, 2.5 to 3 years. Because of natural mortality during this period, harvests and success under a full curl regulation would never be as high as those under 3/4 curl regulations.

6. A conservative estimate of full curl ram production in Alaska's Dall sheep herds is 1,150 rams. This estimated, ideal harvest is numerically equal to the present harvest of rams in Alaska under the 3/4 curl regulation.

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Appendix I. Areas defined within mountain ranges of Alaska for purposes of Dall ram horn growth study.

Alaska Range East - ARE

ARE I - The drainages of the Yanert Fork of the Nenana River, Healy River, Wood River, Dry Creek, Little Delta River, Delta Creek and the western drainages of the Delta River from Ann Creek on the south to McGinnis Creek on the north.

ARE II - The eastern drainages of the Delta River from Rainbow Ridge on the south to Ruby Creek on the north, Jarvis Creek, Gerstle River, Little Gerstle River, Johnson River and the Granite Mountains.

ARE III - The drainages of the Robertson River, the southern drainages of the Tanana River from the Robertson River east to the Tok Slana Highway, Clearwater Creek, Tok River and the Slana River.

Alaska Range West - ARW

ARW I - The drainages of the Mulchatna River and Chilikadrotna River.

ARW II - The drainages of the Stony River, Swift River, Big River, Middle Fork of the Kuskokwim and South Fork of the Kuskokwim.

Brooks Range - BRR

BRR I - The drainages of the Noatak River and the Kobuk River.

BRR II The drainages of the Middle Fork of the Koyukuk River including the John River, Wild River and North Fork of the Koyukuk River. The drainages of the West Fork of the Chandalar River North Fork of the Chandalar River and the western drainage of the East Fork of the Chandalar upstream to the Junjik River. The eastern drainage of the Chandler River, Tuluga River, Kanayut River, Nanushuk River, Itkillik River, Kuparuk River, Toolik River, Sagavanirktok River and the western drainages of the Ivishak River.

BRR III - The eastern drainages of the East Fork of the Chandalar River, Sheenjek River, Coleen River. The drainages of the Canning River, Hulahula River, Jago River, Aichilik River, Egakshak River and the Kongakut Rivers.

Chugach Mountains - CMR

CMR I - The drainages of Bird Creek, Penguin Creek, Indian Creek, Campbell Creek, Ship Creek, Eagle River, Peters Creek, Eklutna River and Lake.

CMR II - The drainages of the Nelchina River and Glacier, Tazlina River and Glacier, Kiana Creek, Klutina River and Tonsina River.

CMR III - The drainages of Bremner River, Tebay River, Hanagita River, Tana River, and southern drainages of Chitina River including the south side of Logan Glacier.

Talkeetna Mountains - TCW

TCW I - The western drainages of the Chickaloon River, Talkeetna River and the drainages of the Kings River, Granite Creek, Little Susitna Creek, Willow Creek, Peters Creek, Kashwitna River and Sheep River.

TCW II - The eastern drainages of the Talkeetna and Chickaloon rivers, the drainages of Kosina Creek, Black River, Oshetna River, Little Nelchina River, Caribou Creek, Hicks Creek and Boulder Creek.

Wrangell Mountains - WMR

WMR I - The drainages of the Mentasta Mountains, Copper River, Nabesna River, Chisana River, Snag Creek and White River.

WMR II - The drainages of the Sanford River, Nadina River, Dadina River, Chetaslina River, Cheshnina River, Kotsina River, Kuskulana River, Lakina River, Kennicott River, Root Glacier and the western drainages of the Nizina River.

WMR III - The eastern drainages of the Nizina River, Chitistone River, Canyon Creek, MacColl Ridge, Hawkins Glacier, Barnard Glacier, Anderson Glacier and the Chitina Glacier.

Tanana Hills-White Mountains - THW

THW I - The drainages of the Charley River, Seventymile River, Salcha River, East Fork of the Chena River, Birch Creek, North Fork of the Fortymile River.

THW II - The drainages of Beaver Creek, Victoria Creek, Preacher Creek and Mt. Schwatka.

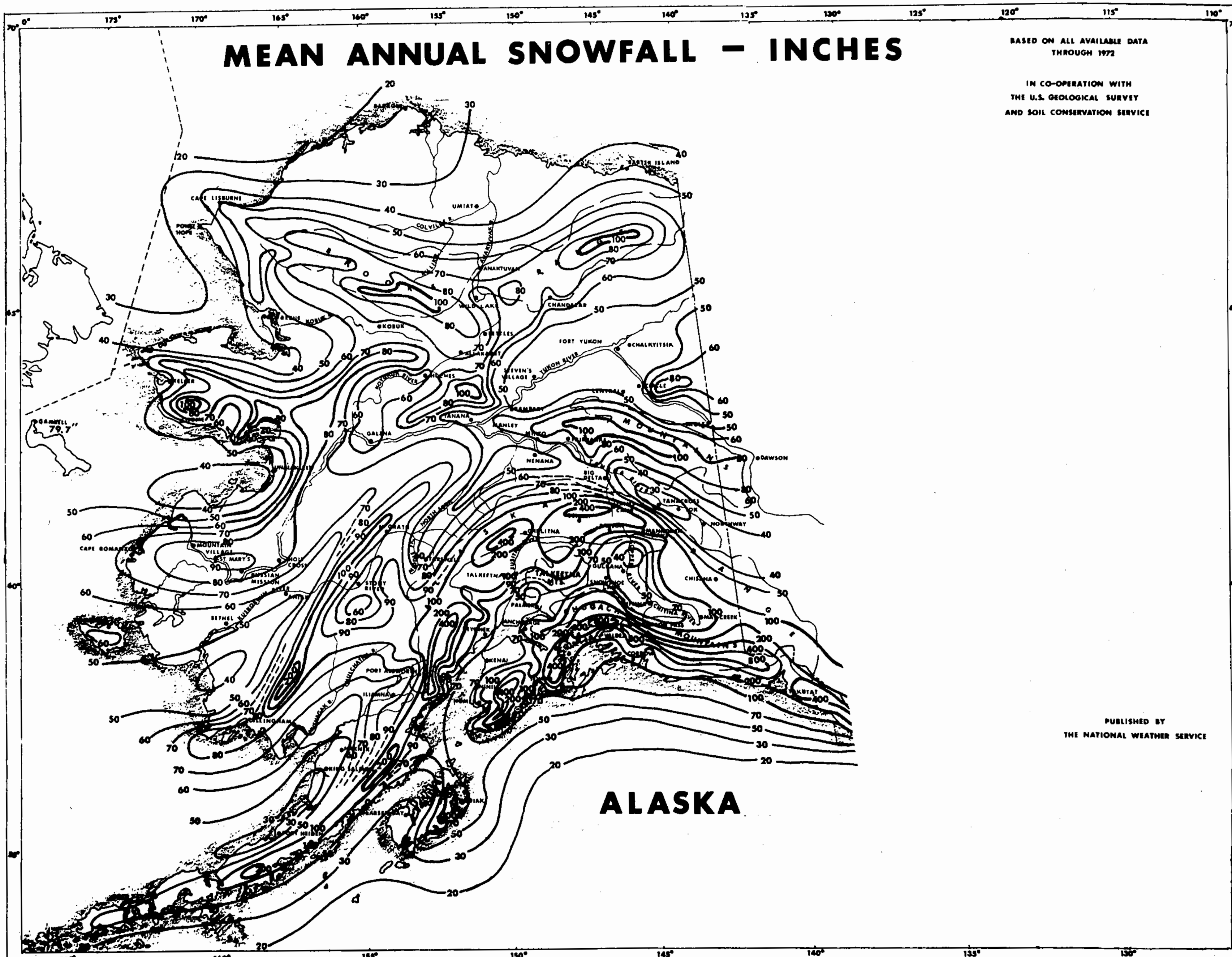
Kenai Mountains - KMR

KMR I - The drainages of Resurrection Creek, Sixmile Creek, Canyon Creek, Johnson Creek, Granite Creek, Quartz Creek, Crescent Lake, Kenai Lake, Upper Trail Lake, Grant Lake, Ptarmigan Lake, Sheep Mountain, Lost Lake, Cooper Lake and Russian Mountain.

KMR II - The drainages of Grewingk Creek and Glacier, Portlock Glacier, Dixon Glacier, Kachemak Glacier, Sheep Creek, Dinglestack Glacier, Fox River, Chernof Glacier, Tustumena Lake and Glacier, Indian Creek, Killey Creek and the Skilak River and Glacier.

Appendix II. Listing of areas within each mountain range according to rank by parameter (BRR I, CMR III and TCW III excluded because of small sample sizes).

	RANKING BY PARAMETER			
Mt. range/area	Mean vol. at 7 yrs.	Expected max. volume	Ave. max. sustained horn growth	Mean diameter horn curl
Alaska Range East				
ARE I	13	15	18	11
ARE II	5	9	8	5
ARE III	2	5	3	2
Alaska Range West				
ARW I	17	18	17	17
ARW II	10	17	16	15
Brooks Range				
BRR II	12	10	15	6
BRR III	14	12	10	3
Chugach Mountains				
CMR I	16	13	11	13
CMR II	7	1	2	8
Kenai Mountains				
KMR I	15	14	13	14
KMR II	6	11	5	4
Talkeetna Mountains				
TCW I	4	2	4	10
TCW II	18	7	14	16
Tanana Hills-White Mts.				
THW I	3	6	7	12
THW II	9	8	6	7
Wrangell Mountains				
WMR I	11	16	12	9
WMR II	8	4	9	18
WMR III	1	3	1	1



Appendix III. Mean annual snowfall listed by mountain range and area.

Appendix IV. Alaska Dall ram harvest and hunter numbers since 1967.

Year	Rams harvested	Number of hunters
1967	922	2843
1968	1122	3353
1969	955	2980
1970	988	2672
1971	1079	3111
1972	1132	3125
1973	1127	3172
1974	1243	2949
Average	1071	3026

Appendix V. Average ages at 3/4 and full curl for rams by area within each mountain range.

Mt. range/area	Age at 3/4 curl (horn growth years)	Age at full curl (horn growth years)	Difference (years)
Alaska Range East			
ARE I	5.9	8.7	2.8
ARE II	5.6	8.7	3.1
ARE III	5.1	8.5	3.4
Alaska Range West			
ARW I	5.1	7.6	2.5
ARW II	5.6	8.6	3.0
Brooks Range			
BRR II	6.8	10.0	3.2
BRR III	6.5	9.3	2.8
Chugach Mountains			
CMR I	5.4	8.5	3.1
CMR II	4.8	7.3	2.5
Kenai Mountains			
KMR I	4.8	7.5	2.7
KMR II	5.5	8.3	2.8
Talkeetna Mountains			
TCW I	5.3	7.5	2.2
TCW II	5.2	8.0	2.8
Tanana Hills-White Mts.			
THW I	5.5	8.0	2.5
THW II	5.8	10.5	4.7
Wrangell Mountains			
WMR I	5.4	8.0	2.6
WMR II	4.3	6.8	2.5
WMR III	4.9	7.0	2.1

Appendix VI. Average ages of sheep harvested by mountain range (sample size in parentheses).

Mountain range	1968	1969	1970	1971	1972	1973	1974
Alaska Range East	7.4(29)	6.8(43)	7.9(53)	7.5(26)	7.3(62)	7.2(43)	6.8(44)
Alaska Range West	7.2(21)	8.4(5)	8.2(9)	7.5(8)	–	8.1(35)	9.3(12)
Brooks Range	7.8(22)	9.0(18)	8.5(24)	8.7(29)	9.6(44)	8.1(35)	8.9(82)
Chugach Mountains	6.5(29)	7.7(31)	5.6(19)	–	6.2(33)	5.3(86)	6.6(18)
Kenai Mountains	–	6.8(17)	6.1(13)	–	–	5.4(18)	6.1(17)
Talkeetna Mountains	6.5(29)	6.7(6)	7.5(17)	–	–	5.1(11)	5.5(24)
Tanana Hills-White Mountains	–	–	8.2(5)	–	–	–	–
Wrangell Mountains	6.6(42)	7.3(19)	6.4(54)	7.0(40)	7.2(43)	6.7(58)	6.6(71)