# Can Horn Length of Mountain Goats Be Used as a Measure of Habitat Quality?

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***Abstract:*** We compared the horn growth of mountain goats (*Oreamnos americanus*) from two areas with different histories and levels of habitat quality. In 1952 and 1953, 18 goats were introduced to Kodiak Island, Alaska. The population now numbers around 1,900 goats and continues to increase. Animals for this transplant were taken from the Kenai Peninsula, Alaska, where goats have been widespread for centuries and are sympatric with Dall sheep (*Ovis dalli*). The Kenai population of roughly 3,000 animals decreased by about 30% over the past 15 yr. We predicted that horn growth on Kodiak, where the habitat is of higher quality, would exceed the growth on Kenai. We measured the length of the first 3 growth increments from horns in both populations from 1998 to 2005. The first horn increment, representing the first 1.5 yr of growth, was highly correlated with and inversely related to the 2 subsequent yearly growth increments. Kodiak goats had longer horn growth than Kenai animals but the difference was greater for females than males. Initial horn growth of mountain goats may be a useful index of habitat quality.

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Horn and antler growth has been correlated with nutrition for cervids (Moen and Pastor 1998, Schmidt et al. 2001, Bartoskewitz et al. 2003, Weladji et al. 2005) and bovids (subfamily Caprinae: Wishart and Brochu 1982, Bayer and Simmons 1984, Hoefs and Nowlan 1997, Hook 1998, Giacometti et al. 2002). Past work in the genus *Ovis* has shown a variety of methods for describing how habitat may influence horn growth. Variation in horn growth was correlated to primary productivity of forage for Dall sheep (Bunnell 1978). Bighorn sheep (*Ovis canadensis*) had greater annual horn growth when introduced onto new habitat compared to horn growth in parent populations (Picton 1994, Hook 1998), and horn growth may decrease when population densities increase (Jorgenson et al. 1998). Bighorn sheep may defer horn growth and put energy into maintenance when food is limited (Festa-Bianchet et al. 2004).

Relatively few studies related habitat to variation in horn growth in mountain goats. Foster (1978) found differences between male and female goats in the first 1.5 yr of horn growth but did not make regional comparisons. Côté et al. (1998) found lactation negatively affected horn growth but total rainfall had no effect. The nutritional state during the initial years of growth can alter the size and proportions of mountain goat skulls (Cowan and McCrory 1970), and horn length may be correlated to body weight (Bunnell 1980, Houston and Stevens 1988).

Mountain goat populations often exhibit high growth rates when introduced to new habitat (Adams and Bailey 1982, Swenson 1985, Williams 1999). Mountain goats on Kodiak Island increased rapidly after 7 males and 11 females were introduced in 1952 and 1953. They currently number around 1,900 animals and inhabit most of the available habitat on the island. The goat population on the Kenai Peninsula ranges throughout the Kenai Mountains. The current population of approximately 3,000 animals decreased 30% over the past 15 yr (McDonough 2004). This decline may be due to a decrease in habitat quality but could also be due to an array of contributing factors. Kenai goats potentially compete with approximately 1,500 sympatric Dall sheep (Dailey et al. 1984, Laundré 1994). Both species have been present on the Kenai for centuries; native people hunted them long before Alaska was settled by Russians in the late 1700s (Sherwood 1974) and large numbers were documented during early explorations over a century ago (Bennett 1918). Although there are similarities in goat habitat and climate of these 2 regions, both the quality of the summer habitat and the availability of winter range due to typical snow accumulation are lower in the Kenai Mountains compared to Kodiak (Hjeljord 1973). Our objectives were to quantify the early sex and age-specific growth of goat horns and compare this growth between the 2 populations. We made the assumption that horn growth primarily is a function of resource availability (Bunnell 1978; 1980). We hypothesized early horn growth in Kodiak goats would be longer than in Kenai animals.

**Study areas**

Kodiak Island (13,000 km$^2$) and the Kenai Peninsula (24,000 km$^2$) are in southcentral Alaska (Figure 1). Each has a maritime climate. Precipitation is greater along the coast and varies inland with elevation and distance from the coast. The average precipitation on both areas ranges from about 1,270 to 1,780 mm/year (www.ambcs.org, www.wrcc.dri.edu). The Kenai has slightly warmer summer temperatures and colder winter temperatures. Warmer winter temperatures on Kodiak, often above freezing, result in reduced snow depths, at least at lower elevations, and a longer growing season than on the Kenai Peninsula (Hjeljord 1973).

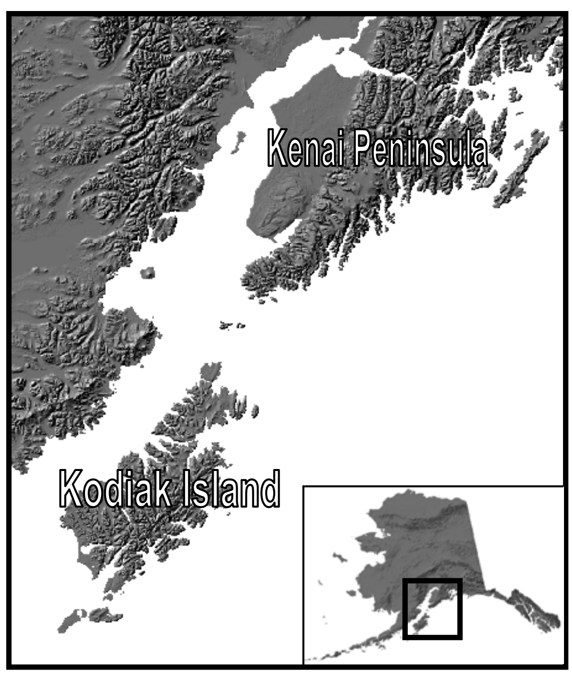


**Figure 1.** Kodiak Island and the Kenai Peninsula in southcentral Alaska, USA.

The Kenai Mountains range in elevation from 1,300 to 2,000 m above sea level. Peaks on Kodiak range from 700 to 1,300 m above sea level. The vegetation on Kodiak and Kenai is similar and was described extensively in Hjeljord (1973). The most apparent difference between the 2 areas is the limited occurrence of coniferous forest on Kodiak. Alpine tundra (Viereck and Little 1972) covers most higher elevations at both sites. Preferred forage species for goats were more abundant on Kodiak than on the Kenai Peninsula (Hjeljord 1973).

**Methods**

Counting horn annuli is an accurate method for aging Dall sheep (Geist 1966) and mountain goats (Brandborg 1955, Stevens and Houston 1989). Due to decreasing horn growth with age, total horn length increases only slightly after the age of 3.5 yr for mountain goats (Côté et al. 1998). Therefore, we measured the length of the outside curve of the horn for the first 3 growth increments of goats from Kodiak Island and the Kenai Peninsula from 1998 to 2005. Measurements were taken only on the longer of the 2 horns from goats legally killed by hunters. We did not include broken or broomed horns. Each of the 3 increments corresponds to 1 yr of horn growth except for the first measurement from the tip of the horn to the first discernable annulus that develops during the goat's second winter (Brandborg 1955). We analyzed horn growth using 2-way ANOVA models that included the effects of sex, region (Kodiak and Kenai), and their interaction on horn length. We used Pearson's product-moment analysis to measure correlations among the first 3 growth increments.

We also describe historical data of population size and hunter harvest for these 2 populations. Goat surveys were conducted with fixed-winged aircraft using techniques described in Nichols (1980). Goat surveys were conducted each year on 20 to 40% of the Kenai Peninsula and 40 to 80% of Kodiak. Survey data from Kenai Fjords National Park (2,460 km$^2$) within the Kenai Peninsula were sporadic and not included in this study. Due to the inability to estimate goats not seen during flights, our survey techniques produce minimum counts and not population estimates. Harvest and survey data for goats are maintained by the Alaska Department of Fish & Game (www.wildlife.alaska.gov).

**Results**

We measured 988 horn increments on 402 individual mountain goats. Our results were comparable to previous studies that identified sex differences in early horn growth in mountain goats (Brandborg 1955, Cowan and McCrory 1970). A notable similarity was that the first growth increment in males was greater than in females, and females exhibited greater growth in the second and third increments than did males (Hoefs et al. 1977, Foster 1978, Côté et al. 1998) (Figure 2). Kodiak females had longer horn length after 2.5 yr than Kenai females, and males from both populations (Figure 2).

We did not compare each growth increment separately because the growth of the increments was highly correlated. Most notably, there was an inverse relationship between the length of the first measured horn increment (0-1.5 yr) and the subsequent 2 yr (Figure 3). Correlation trends seen in Figure 3 were the same when the data were analyzed separately by region (Kenai and Kodiak) and by sex. The effects of sex, region, and their interaction on only the first horn growth increment were all significant (Table 1). The first increment on Kodiak females (165.2 mm, 95% CI: 161.6-

**Table 1.** ANOVA of horn length of mountain goats from the Kenai Peninsula and Kodiak Island, Alaska, USA, 1998 to 2005. Effects of the variables on growth of the first horn increment (0-1.5 yr) and summation of the first 3 increments (0-3.5 yr).

| | First increment only[1] | | | First 3 increments[2] | | |
|---|---|---|---|---|---|---|
| Variable | df | *F* | *P* | df | *F* | *P* |
| Sex | 2 | 21892.3 | < 0.001 | 2 | 33237.8 | <0.001 |
| Region | 1 | 40.1 | < 0.001 | 1 | 9.9 | 0.002 |
| Sex X region | 1 | 9.5 | 0.002 | 1 | 7.9 | 0.005 |

[1] 108 male and 52 female goats from Kenai; 165 male and 77 female goats from Kodiak.
[2] 64 male and 38 female goats from Kenai; 99 male and 53 female goats from Kodiak.

168.8) was 17.8 mm greater than Kenai females (147.4 mm, 95% CI: 143.0-151.8). The first increment on Kodiak males (176.0 mm, 95% CI: 173.5-178.4) was 7.0 mm greater than Kenai males (169.0 mm, 95% CI: 166.0-172.1).

We also conducted an analysis on the combined length of the first 3 increments. This analysis was limited to goats older than 3.5 yr ($n$ = 254). As in the previous analysis of only the first increment, the effects of sex, region, and their interaction on the combined length of all 3 increments were all significant (Table 1). Total length of the first 3 increments on the horns of Kodiak females (222.6 mm, 95% CI: 218.9-226.2) was 11.8 mm greater than females on the Kenai (210.8 mm, 95% CI: 206.5-215.1). The difference for males was much less, showing only a 1.8 mm length difference in Kodiak (216.5 mm, 95% CI: 213.8-219.1) over Kenai goats (214.7 mm, 95% CI: 211.4-218.0).

The Kodiak goat population steadily increased after the introduction in the early 1950s while the Kenai population declined since the early 1990s (Figure 4A). The first hunting season for goats on Kodiak was authorized in 1968 through a limited permit hunt (Van Daele and Crye 2004). Kenai goats have been hunted for centuries but harvest data was recorded only since the late 1960s (Figure 4B). Hunts in both areas have been recently managed through different types and numbers of permits based on minimum population sizes (Del Frate and Spraker 1994). The decrease in the Kenai harvest in the late 1970s was due to introduction of a permit hunt system, which initially was restrictive. The harvest of goats on Kodiak recently surpassed the Kenai Peninsula despite the Kenai's larger land mass and higher goat population size (Figure 4B). The harvest rate based on the minimum number of animals counted in 2005 was roughly 9% for Kodiak and about 4% for the Kenai.

## Discussion

Anual horn growth is driven by a complex interaction of age, energetic demands, genetic variation, and habitat quality (Festa-Bianchet et al. 2004). We assessed habitat quality indirectly by using horn growth as an index. We assumed Kodiak was a higher quality habitat for goats than the Kenai due to favorable climatic differences, relatively unexploited range (Hjeljord 1973), no competition from Dall sheep (Dailey et al. 1984, Laundré 1994), and the continued growth of the Kodiak population compared to the decline of the Kenai population (Figure 4A). This hypothesis was supported by longer horn growth measured in Kodiak goats.

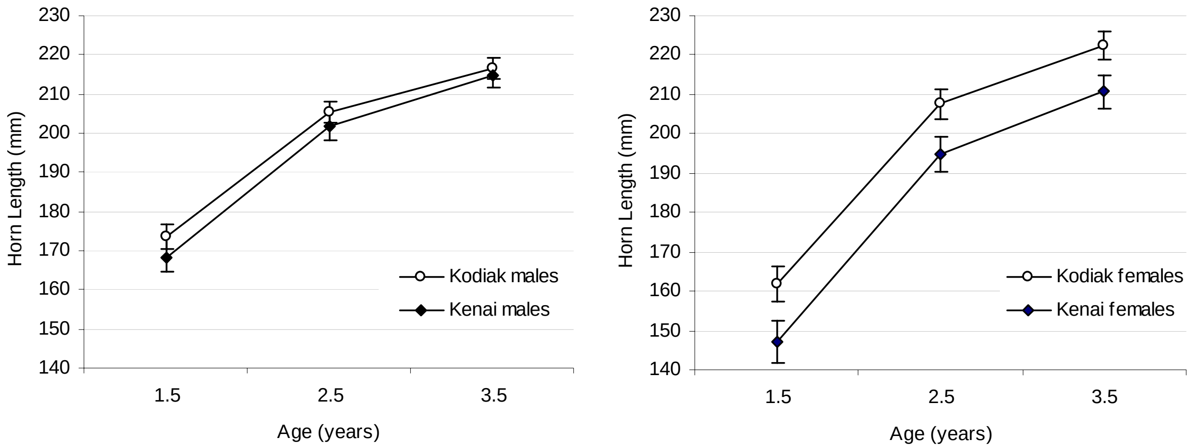


**Figure 2**. Horn length for the first 3 growth increments of mountain goats from Kodiak Island and the Kenai Peninsula, Alaska, USA, 1998 to 2005. Only goats having all 3 increments (>3.5 yr old) were included. 95% confidence intervals shown.

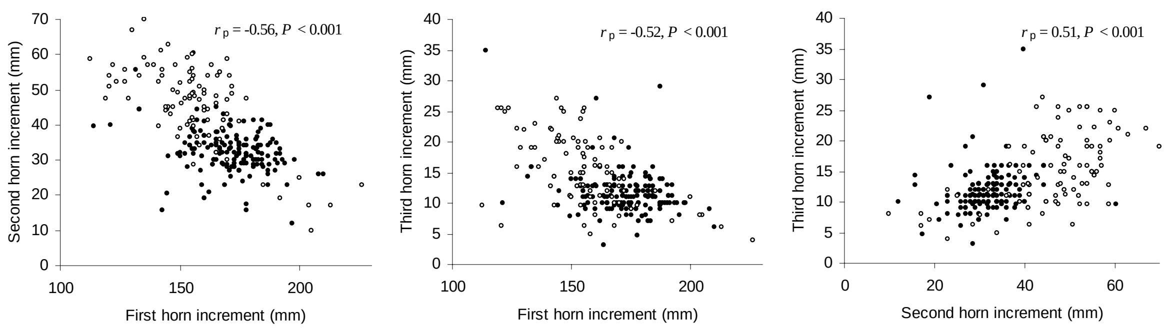


**Figure 3**. Correlations of the first 3 horn-growth increments from mountain goats on Kodiak Island and the Kenai Peninsula, Alaska, USA, 1998 to 2005. Open circles - females, solid circles - males. Pearson correlation coefficients ($r_p$) and significance levels shown.

We found growth of the first horn increment was inversely correlated with growth in the subsequent 2 yr. This pattern was seen in Dall sheep (Bunnell 1978, Bayer and Simmons 1984), mountain goats (Côté et al. 1998), Bulgarian chamois (*Rupricapra rupricapra*: Massei et al. 1994), and Cantabrian chamois (*R. pyrenaica*: Pérex-Barberia et al. 1996). Most horn growth studies in the genus *Ovis* focus on males due to their much greater horn growth than females (Bunnell 1978, Bayer and Simmons 1984, Picton 1994). Bunnell (1978) found horn growth in male Dall sheep to be more strongly affected by environmental differences than in females. Mountain goats do not share the degree of horn dimorphism found in Dall sheep so it is appropriate to consider both sexes when evaluating variation in horn growth across populations. We found a significant interaction between region (Kenai and Kodiak) and sex where strong differences were largely between females of these 2 populations.

The first horn increment in the population of Kodiak females was about


**Figure 4**. Mountain goat survey (A) and harvest (B) data from Kodiak Island and the Kenai Peninsula, Alaska, USA, 1968 to 2005.

10% longer (17.8 mm) than for Kenai females. When all 3 increments were combined, the horn length of Kodiak females was about 5% longer (11.8 mm) than Kenai females. Differences between males in the two populations showed longer growth on Kodiak but the discrepancy was minor compared to females. Kodiak females had longer horns after 2.5 yr than male goats from either population. Our data suggests the higher quality habitat on Kodiak primarily affects female horn growth and is somewhat negligible in males.

Animals in the subfamily Caprinae can both break the tips of their horns and also wear them down over time (Brandborg 1955, Schaller 1977). However, horn tip wear in mountain goats may be limited (Côté et al. 1998). We believe horn wear did not bias our results because we did not include animals with broomed or broken horns. Moreover, assuming tip wear is constant over time, we found no differences in the ages of goats sampled between the two populations. The ages of measured females for Kenai (mean = 5.6 yr) and Kodiak (mean = 5.9 yr) were not statistically different ($t$ = 0.6, df = 125, $P$ = 0.26) nor were there differences between males on Kenai (mean = 4.4 yr) and Kodiak (mean = 4.4 yr) ($t$ = 0.2, df = 229, $P$ = 0.43). There may be a bias in using goats killed by hunters if they are not representative of the population. Hunters ostensibly choose to take the largest goat they can. If this bias exists, it would have occurred in both populations. However, considering the large variation in horn size and ages of animals measured in our study, which included many yearlings not used in our analyses, we do not believe this biased the results of our study.

Genetic variation was the primary explanation for differences in horn growth between 2 populations of Dall sheep in the Yukon Territory, Canada (Hoefs and Nowland 1997). Furthermore, small horn size in some bighorn sheep populations may be due to genetic bottlenecks (Stewart and Butts 1982) or low heterozygosity (Fitzsimmons et al. 1995). Mountain goats used to populate Kodiak Island were taken from the Kenai Peninsula, but we do not know the possible effects of introducing so few individuals.

It is noteworthy that female mountain goats on Kodiak in an apparently high-quality habitat dedicate a portion of their annual energy budget to horn growth above those in a lower quality habitat, even as they approach reproductive age. Female mountain goats reproduce once a threshold body weight is achieved, irrespective of age (Houston et al. 1989), and there is a modest but positive correlation between horn length and body weight (Houston and Stevens 1988). We do not know if the greater horn growth in Kodiak goats occurred independent of or along with a greater body size. However, it is possible that energy devoted to horn growth for female goats on Kodiak may represent surplus energy only available in high-quality habitats. Data on age of first breeding for female goats in both our populations along with data on body size would be needed to properly address these questions.

## Management implications

Horn length is used widely as an index of habitat quality (Bunnell 1978, Wishart and Brochu 1982, Côté et al. 1998). For mountain goats, the first 1.5 yr of horn growth is cited as a measure of "population quality" (Foster 1978). The higher quality habitat on Kodiak, as measured by horn length, was detected in the first 1.5 yr of horn growth and when the first 3.5 yr were combined. However, differences in horn length between our populations were greater when only the first 1.5 yr of growth were analyzed due to the inverse relationship between this initial growth and the 2 subsequent yr. Horn growth is more deterministic in mountain goats than in wild sheep species. It is not clear if there is a benefit for an individual to grow long horns. Indeed, horn growth may not be important in sexual selection (Côté et al. 1998). It may be adaptive in high quality habitats to put some surplus energy into early horn growth and then defer energy into body size and reproduction. Horn growth between the first two winters of life is typically the longest growth increment in mountain goats. If fast initial horn growth in high quality habitats allows an individual to redirect energy to growth in body size or early reproduction, the first 1.5 yr of horn growth may indeed be a good measure of habitat quality.

Mountain goats typically do not grow horns longer than 26 to 28 cm, although there can be large variation within a population, especially when the population has a large and heterogeneous range. Considering the horn growth differences of 2 cm or less in our study, detectable differences in horn growth for mountain goats might be limited to studies with large sample sizes. Our study contributes to other work that identified differences in the dynamics of introduced and native mountain goat populations (Adams and Bailey 1982, Swenson 1985, Williams 1999).

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