POPULATION AND HABITAT ANALYSES FOR DALL'S SHEEP (*OVIS DALLI*) IN WRANGELL – ST. ELIAS NATIONAL PARK AND PRESERVE

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POPULATION AND HABITAT ANALYSES FOR DALL'S SHEEP (*OVIS DALLI*) IN WRANGELL – ST. ELIAS NATIONAL PARK AND PRESERVE

A

THESIS

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ABSTRACT

We summarized and statistically analyzed historical fixed-wing aerial surveys (1949-2002) and harvest records (1983-2002) of Dall's sheep (*Ovis dalli dalli*) from Wrangell-St. Elias National Park and Preserve (WRST). Among survey units there were significant differences in observed densities, hunter-reported harvest, horn lengths of harvested rams, and horn length residuals from the regression of length on age. There was no consistent evidence of net change in WRST-wide sheep density, even though some survey units showed trends in density. Reported harvest in WRST declined linearly during 1973-2003 from 376 to 139 rams per year.

We estimated the relationships among population and habitat characteristics with multiple linear regression. We standardized all variables and evaluated all 1, 2, and 3 variable models using Akaike's Information Criterion for small sample sizes (AICc) for model selection. The best model for sheep density showed a positive correlation with median NDVI (relative vegetation greenness) and terrain ruggedness. The same model resulted from examining adult and lamb cohorts separately. Approximately 50% of horn length was explained by age. The habitat variables estimated did not explain a significant amount of the variance observed in reported harvests or horn length residuals from the regression of length on age.

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LIST OF ABBREVIATIONS

ADF&G	Alaska Department of Fish and Game
AICc	Akaike's Information Criterion corrected for small sample size (Burnham & Anderson 1998)
Δ_i	The difference between the top model and subsequent models when using Akaike's Information Criterion (Burnham & Anderson 1998)
DEM	Digital Elevation Model (60m resolution)
FN	fecal nitrogen
GIS	Geographic Information Systems
GMU	Game Management Unit
MODIS	Moderate Resolution Imaging Spectroradiometer
NED	National Elevation Dataset (30m resolution)
NDVI	normalized difference vegetation index
NDF	neutral detergent fiber
NIR	near-infrared reflectance
NPS	National Park Service
RUG1	terrain ruggedness described by surface: planar area ratio
RUG2	terrain ruggedness described by vector analysis of slope and aspect (Hobson 1972)
SD	standard deviation
SE	standard error

SU	survey units
TM	Thematic Mapper
UAF	University of Alaska Fairbanks
UCU	ADF&G harvest uniform coded units
USGS	United States Geological Survey
VIS	visible red reflectance
w_i	relative weight of models using Akaike's Information Criterion (Burnham & Anderson 1998)
WRST	Wrangell-St. Elias National Park and Preserve
$\overline{X}$	sample mean

PREFACE

This thesis is composed of two chapters written as separate manuscripts. Chapter two is being submitted for publication to The Journal of Wildlife Management (JWM). Chapter one is also in JWM format as per thesis guidelines although there are no plans to submit it for publication. In addition to those acknowledged at the end of each chapter I would like to thank those who made important contributions to the overall success of my thesis. My field assistants and Wrangell-Mountain Air provided much needed assistance in sometimes less then favorable conditions. Outfitters Urban Rahoi, Riley Knighton, and Paul Klaus provided me with their insights as well as field assistance. I am indebted to Devi Sharp, Chief of Resources at Wrangell-St. Elias National Park and Preserve, whose support made the whole project possible. Thanks to my advisor Dr. Brad Griffith for his persistence and my committee members Drs. Ed Murphy and Dave Verbyla for their editorial assistance. I am grateful for the assistance of various Department of Biology & Wildlife and Alaska Cooperative Fish & Wildlife Research Unit during the course of this project, especially Michelle Das and Carol Piser. A special thank you goes to my family and friends who encouraged and supported me along the way – this thesis is dedicated to you. I couldn't have done it without you.

GENERAL INTRODUCTION

U.S. National Parks in Alaska have a mandate to maintain “natural and healthy” wildlife populations (Alaska National Interest Lands Conservation Act 5 sec. 8-03, 805 and 815, 1980). In order to fulfill this mandate it is important to know the status of Dall’s sheep (*Ovis dalli dalli*) populations. Long-term data on Dall’s sheep in Wrangell-St. Elias National Park and Preserve (WRST) existed but had not been fully analyzed since the formation of the park in 1980. Analysis of aerial survey and harvest records may provide an understanding of both present status and historical trends within WRST. We used Geographic Information Systems (GIS) and remote sensing to inventory the habitat characteristics of aerial survey units.

The relationships among large-scale habitat attributes and population characteristics had not been estimated for Dall’s sheep. Our purpose was to estimate the relationships among sheep population characteristics (density, reported harvest, and reported horn length of harvested rams) and habitat attributes of sheep survey units in WRST using 1967-2002 aerial survey data and 1983-2002 harvest reports. In addition to the escape terrain attributes estimated by McKinney *et al.* (2003), we considered landcover, aspect, relative greenness, and two different estimates of terrain ruggedness. We used Akaike’s Information Criterion (AIC, Akaike 1973, Burnham and Anderson 1998) for multiple linear regression model selection to estimate the relationship among Dall’s sheep population and habitat attributes.

CHAPTER I.

DENSITY, HARVEST, AND HORN DIMENSIONS OF DALL'S SHEEP IN WRANGELL ST. ELIAS NATIONAL PARK AND PRESERVE, ALASKA

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Abstract: Historical fixed-wing aerial surveys (1949-2002) and harvest records (1983-2002) of Dall's sheep (*Ovis dalli dalli*) in Wrangell-St. Elias National Park and Preserve have not been fully summarized or statistically analyzed since the formation of the park. Densities and lamb:ewe ratios were estimated for 30 survey units while reported harvest and horn dimensions of harvested rams were estimated for 28 survey units. The overall mean density was 0.53 sheep/ km^2 with an overall average ratio of 28 lambs:100 ewes. Overall mean lamb density was 0.09 lambs/ km^2, and mean adult density was 0.45 sheep/ km^2. There were significant differences in observed total densities, reported harvest, reported mean horn dimensions, and horn length residuals from the regression of length on age among survey units. Observed densities tended to be greater in the 1980's than other years; this observation may have been dominated by densities in three survey units (11, 12, 14) that peaked in the 1980's and have since declined. The mean annual reported sheep harvest from 1983-2002, for the entire park, was 334 sheep; rams accounted for 70.2% and ewes 3.3% of harvest, with the remainder being of unreported sex. Reported harvest declined linearly from the 1973-2002. Rams harvested from WRST during 1983-2002 had an average reported horn length of 85 cm (33.5 in), basal circumference of 32 cm (13 in), and age of 8 years.

Key Words: aerial surveys, Alaska, Dall's sheep, density, harvest, horn dimensions, lamb:ewe ratios, mountain sheep, *Ovis dalli*, thinhorn, Wrangell-St. Elias National Park and Preserve, WRST

Approximately 20% of the world's and 25-35% of all Alaskan Dall's sheep (*Ovis dalli dalli*) occur within Wrangell-St. Elias National Park and Preserve (WRST), a place renowned for its trophy sheep (Heimer and Smith 1975, Murphy and Dean 1978, Batin 1989, Mitchell 1998, 1999, and 2000). In spite of the importance of Dall's sheep to sport and subsistence hunting, visitor experience, local economies (National Park Service 1988), and a National Park Service (NPS) mandate to maintain "natural and healthy" wildlife populations (Alaska National Interest Lands Conservation Act 5 sec. 8-03, 805 and 815, 1980), existing aerial survey data for WRST and harvest reports have not been fully summarized since the formation of the park in 1980.

Aerial survey and harvest records on Dall's sheep in WRST have been collected by various agencies over the past 5 decades. Within WRST there are 34 sheep survey units originally delineated by Alaska Department of Fish and

Game (ADF&G) in 1949. Surveys were conducted sporadically between 1949 and 1966 and more frequently after 1967. Surveys were not always conducted annually and did not cover all survey units uniformly given time and funding constraints. Prioritization of survey units has been based on hunter use, visitor access, and research goals. Thus, data available per survey unit ranged from 0-15 years. Currently, fixed-wing surveys are flown cooperatively by NPS and ADF&G.

Successful sheep hunters (both sport and subsistence) in WRST are required to record and submit harvest data on sex, diameter of horn at base, length of horn, age of animal, and location where the animal was killed. Location was coded by ADF&G to a uniform coded unit (UCU) which is a sub-unit within a game management unit (GMU) based on water drainages. The survey units in WRST are located in GMUs 11 and 12. Before 1983, ADF&G UCUs were not well defined spatially and were different from those used currently (Brian Lieb, ADF&G *person. comm.*). For this reason we only used harvest records from 1983 through 2003.

Our purpose was to summarize survey and harvest records to estimate population characteristics (density, lamb:ewe ratios, reported harvest, reported horn dimensions, and reported age of harvested rams) of sheep within survey units and to test for differences in these characteristics among survey units and years. Only the most consistent data, i.e., from the same survey areas using the same methods, were used in the analyses.

STUDY AREA

Located in Alaska, and centered approximately 322 kilometers east of Anchorage and 193 kilometers northeast of Valdez, Wrangell – St. Elias National Park and Preserve (WRST) is bordered by the Gulf of Alaska coastline, the entire eastern half of the Copper River drainage, the Canadian border to the west, and the Richardson highway to the east (National Park Service 1986). The largest U.S. National Park, WRST (Fig. 1.1), was established in 1980 ecompassing 5,341,850 hectares, approximately six times the size of Yellowstone National Park (National Park Service 1986). Despite its size it is only penetrated by two unpaved roads: the McCarthy and the Nabesna roads. Few roads and the ruggedness of the country result in few visitors and relatively undisturbed conditions for wildlife. WRST is divided into park and preserve areas (Fig. 1.1). The preserve areas were established around areas of high traditional use, private in-holdings, and villages. Sport hunting is allowed only in the preserve, but subsistence hunting is allowed within both park and preserve (Alaska National Interest Lands Conservation Act 5 sec. 8-03, 805 and 815, 1980).

WRST is dominated by the eastern portion of the Chugach Range, the western portion of the St. Elias Range, the Wrangell Mountains, and the eastern end of the Alaska Range (the Nutzotin Mountains, Fig. 1.2). The Chugach Range is heavily glaciated and has a maritime climate, which is typified by heavy snowfall, warm winters and cool summers (National Park Service 2004) and does not support substantial sheep populations (Mullen and Cella 1984). The St. Elias and Wrangell Ranges both lie within a transitional climate zone; their southern flanks receive heavy snowfall while the northern flanks lie within a precipitation shadow (National Park Service 1998). These ranges are legendary among hunters for their sheep populations and Boone and Crockett Club trophies (Nesbitt and Parker 1977, Murphy and Dean 1978, Batin 1989). The Nutzotins are in the interior climate zone, typified by dry, cold winters and hot summers. These, the lowest elevation mountains within WRST, do not have extensive glaciers (National Park Service 1998) and support large populations of sheep.

Dall's sheep inhabit dry, mountainous terrain (Geist 1971, Hoefs 1984, Hoefs *et al.* 1975, Lord and Luckhurst 1974, Murie 1944). In the St. Elias, Wrangell, and Nutzotin ranges, sheep predominately use four types of habitat which are available in all 4 mountain ranges: 1) smoothly contoured, open, graminoid covered slopes, 2) steep, broken cliffs, and 3) sparsely vegetated talus slopes, and 4) ridges at high elevations (Geist 1971).

METHODS

Aerial Survey Data

Field data were collected from ADF&G and NPS files and official reports, sorted, and entered into an Excel (Microsoft® 1997) database. Survey unit boundaries were estimated using topographic maps and personal communication with previous and current biologists and pilots. Thirty-four survey units were digitized for use with Geographic Information Systems (GIS) and formalized in writing for current and future use by all agencies concerned (ADF&G Glennallen, ADF&G Tok, WRST). Only surveys that attempted a complete census of all sheep in a survey unit were used to estimate densities and lamb:ewe ratios. Areas that had been subdivided for concentrated research efforts and those where boundaries were vague were not used. When more than one survey was flown in a given year we selected data from the most experienced observer (i.e. who was on record as having flown more surveys within WRST) to avoid duplication. Data were not averaged as differences between some survey results were quite large. Where raw data conflicted with summaries we used raw data. Specific surveys used in data analyses are presented in Appendix E.

Information available for most surveys included number of sheep observed, sex and age classification (ewes, lambs, yearling rams, 1/2-3/4 curl rams, 3/4-7/8 curl rams, full curl rams, and unknown), date of survey, pilot name, aircraft type, observer name, and survey unit. In some cases classification information was not available and only the total number of sheep observed was recorded. All surveys were conducted in summer between 14 June and 8 August 1949-2002 with the exception of 2 surveys in 1967 which were flown 30 November and 1 December. As the numbers reported for the winter surveys were very similar to those reported in summer surveys and survey units are large enough to encompass both summer and winter ranges we included them in our analyses. For consistency only surveys conducted from fixed-wing aircraft (the bulk of the surveys) were used for this study. Data from surveys conducted by helicopter or by foot were not used in density estimates, as McDonald *et al.* (1991), in a sightability study of sheep in WRST, found that observers in helicopters missed more animals than those in fixed-wing aircraft and foot surveys rarely covered the full survey unit. Average survey time was approximately 5 hours. Sheep density was estimated on the basis of the actual surface area of survey units which was estimated from 60 meter digital elevation models (DEM) from the USA national elevation dataset (NED) using Jenness Enterprises' Surface Tools extension for ArcView® (Jenness 2004a/b). Temporal trend estimate comparisons among years and survey units utilized those units with ≥3 annual surveys (21 of 34 for densities, 18 of 34 for lamb:ewe ratios, Fig. 1.4).

Harvest Data

Both subsistence and sport hunters reported harvests to ADF&G. Sheep survey units fell within ADF&G Game Management Units (GMUs) 11 and 12. Harvest regulations differed among GMUs as to the curl size of rams that were allowed to be taken. Survey units did not always clearly fall into park or preserve or one GMU. It was not possible to differentiate sport (legal in only in preserve) from subsistence (legal in both park and preserve) harvests from the records.

We estimated mean harvest, horn dimensions, and ages of reported animals harvested from different survey units using these data. Harvest location was recorded by ADF&G as a harvest unit code known as a uniform coded unit (UCU) from hunter reports. The UCUs, established in 1983, completely independent of survey units, were based on drainages and have been digitized for use with a GIS (Fig. 1.5, Brian Lieb, ADF&G *person. comm.*). The UCUs were overlaid onto survey units, and in most cases there were several UCUs per survey unit. The overlap was not perfect; in some cases UCUs overlapped more than one survey unit. The UCUs were assigned to the survey unit with greater overlap where only a small portion (<1.6 km^2) extended into a second survey unit and geography and landcover indicated small likelihood of sheep in that portion. Harvest records were omitted from analysis where UCUs extensively overlapped 2 or more survey units. In some cases this resulted in no data available for survey units known to have considerable harvest. Thus, insufficient data was not necessarily an indication of lack of harvest. Data from female sheep or where the sex was unreported were not used in horn dimension analysis. For harvested rams, we investigated the relationship between reported horn length and age to estimate horn length residuals.

All statistical tests were performed using SAS V.8 (SAS Institute Inc. 1990) and conducted at alpha = 0.05 level. Means and standard errors were estimated in densities, lamb:ewe ratios, reported harvest, and reported horn dimensions. We tested the hypotheses that there were no differences among survey units or years for densities, lamb:ewe ratios, reported harvest, and reported horn length using an Analysis of Variance (ANOVA, Proc GLM). To identify specific year or survey unit differences where the overall ANOVA was significant we used Tukey's pairwise comparison post-hoc test. To test for temporal trends in densities and reported harvest within survey units we used linear regression analyses.

RESULTS

Aerial Survey Data

Descriptions of survey units are presented in Appendix B. Survey units were labeled east and west to imply perceived biological continuity – where possible these areas should be surveyed together. Digitized survey units are available to the public through the NPS Alaska GIS clearinghouse webpage (http://www.nps.gov/akso/gis/index.htm). The same units were also used to survey mountain goats (*Oreamnos americana*), usually concurrently with sheep, within WRST. Planar and surface areas (using 60m DEM) were estimated for each survey unit (Table 1.3).

Population Characteristics

Mean adult density per survey unit was 0.45 sheep/ km^2 (n = 155, SE = 0.03) with a mean lamb density of 0.09 lambs/km^2 (n = 136, SE = 0.01). Mean total density per survey unit was 0.53 sheep/ km^2 (n = 155, SE = 0.03). The mean observed lamb:ewe ratio per survey unit was 28:100 (n = 133, SE = 0.99). Mean observed sheep densities varied significantly among survey units (Table 1.1, Fig. 1.6, ANOVA, $F_{29,94}$ = 12.00, p <0.0001). Total densities tended to be higher in the 1980’s than other decades (1960’s, 1970’s, 1990’s, 2000’s), with

1983 a low year within the 80's (ANOVA, $F_{29,94}$ = 1.51, p = 0.07). This observation may have been dominated by three survey units (11, 12, 14) which exhibited curvilinear trends that peaked in the 1980's and have since declined (Figures C.8, C.9, C.11). Within survey units, there was a linear decline in total density in survey unit 27 (n = 4, slope = -0.008, r^2 = 0.95, p = 0.025, Figure C.21) and a linear increase in total density in survey unit 7W (n = 3, slope = 0.013, r^2 = 0.64, p = 0.03, Figure C.5) and survey unit 20 (n = 6, slope = 0.003, r^2 = 0.83, p = 0.05, Figure C.16). There were no significant differences in lamb:ewe ratios among survey units (ANOVA, $F_{27,73}$ = 0.98, p = 0.50). Overall lamb:ewe ratios were significantly higher in 1970 and 1981 than 2000 and 2001 (ANOVA, $F_{27,73}$ = 1.85, p = 0.02). Graphs of total densities for each survey unit with $\geq$ 3 years of fixed-wing surveys are presented in Appendix C.

Harvest Data

A total of 6,672 sheep were reported harvested during1983-2002 for all of WRST. Of these, 70.2% were rams (4,686 rams reported during 15 of the 20 years), 3.3% were ewes (218 ewes reported during 12 of the 20 years), and 26.5% were of unreported sex (1,768 sheep reported during 19 of the 20 years). On average, 1983-2002, an annual total of 334 (SE=59.9) sheep of all classifications was reported harvested in all of WRST. When combined with Murphy and Dean's (1978) data, reported ram harvest in all of WRST declined linearly from 1973 to 2002 (r^2 = 0.93, Fig 1.7).

There were insufficient data (due to undefined UCUs for survey units 5E, 7E, 19, 28, 30, and 31) to estimate reported harvest for all individual survey units. For those survey units where harvest could be estimated, there were significant differences in mean reported harvest among survey units (Table 1.2, Fig. 1.8, ANOVA, $F_{27,273} = 36.07$, $p < 0.0001$). Three survey units exhibited trends in reported ram harvest. Reported harvest declined by 12 rams/decade in survey unit 4W (slope = -1.58, r^2 =0.72, $p < 0.0001$), by 5 rams/decade in survey unit 9 (slope = -1.56, r^2 =0.78, $p <0.0001$), and increased by 2 rams/decade in survey unit 23E (slope = 0.12, r^2 =0.85, p=0.05) from 1988-2001.

For rams during 1983-2002 (n = 2,675 rams with reported horn length in 15 of the 20 years), average reported horn length was 85 cm (SE = 28.09; 33 inches, SE = 11.06), average reported horn basal circumference was 32 cm (SE = 8.92; 13 inches, SE = 3.51), and average reported age was 8 years (SE = 2, min = 1, max = 20). Reported horn length was positively correlated with reported age (Fig. 1.9, $r^2 = 0.57$). From age 12 onward there was a suggestion that brooming reduced horn length of older rams (Fig. 1.9). Mean horn length residuals from the regression of length on age (hereafter referred to as horn residuals) (Fig. 1.10, ANOVA, $F_{27,2629} = 15.85$, $p < 0.0001$) and mean reported horn length (Table 1.2, Fig. 1.11, ANOVA, $F_{27,2360} = 10.80$, $p < 0.0001$) of reported harvested rams differed significantly among survey units.

DISCUSSION

Juvenile males stay with ewe bands up to 3 years of age and are difficult to distinguish from ewes from the air as they have not yet developed a significant difference in horn length and are "ewe-like" (Woodgerd 1964, Geist 1971, Murphy and Whitten 1976, Mullen and Cella 1984, Strickland *et al.* 1992, Kern *et al.* 1994). The difficulty in distinguishing young rams from ewes limits the usefulness of lamb:ewe ratios when obtained from aerial census data (Festa-Bianchet 1991, Demarchi and Hartwig 2004). Lamb: ewe ratios in WRST were fairly consistent at ~28 lambs:100 ewes, and there were no significant differences among survey units in lamb:ewe ratios or lamb densities. Densities allow for comparison among survey units which raw counts do not.

Reported densities of Dall's sheep in Alaska, British Columbia, and the Northwest Territories range from 0.3-1.1 sheep/km^2 (Geist 1971, Simmons *et al.* 1984, Singer 1984, Lawler *et al.* 2004). Of Alaskan National Parks and Preserves studied in 1984, WRST had the highest densities at 0.7-1.1 sheep/km^2 (Singer 1984). Our estimates of 0.2-1.1 sheep/km^2 were similar. During the 1980's, sheep densities in WRST were relatively low in 1983. This observation was consistent with other reports of Dall's sheep populations in the Yukon Territory where a decline of 30-40% in numbers of Dall's sheep was reported around that time (Demarchi and Hartwig 2004). Specifically, in neighboring Kluane National Park, there was a 25.3% decline in sheep numbers between June 1981 and June 1982 (Burles and Hoefs 1984). Demarchi and Hartwig

(2004) speculated that this decline may have been related to severe winter conditions.

Long term survey data give an index of what “normal” population sizes and fluctuations might be. This information then can be used to pursue management goals of maintaining “healthy and natural” populations by allowing biologists to establish the range of sheep densities. If stable populations are desirable by managers, declining trends in density within survey units may be of concern. However, it is not known whether survey units described discrete populations of sheep as little is known about sheep movement within WRST.

Most (16 of 22) survey units in WRST showed no significant linear trends in density during the periods that surveys were conducted. While three survey units (7W, 20, 27) exhibited statistically significant linear trends in density, both increases and decreases were evident, the slopes of the regressions were small (<0.01 sheep/km^2/year) and these survey units were contiguous with other units. Three other survey units (11, 12, 14) suggested curvilinear trends in density that peaked in the 1980’s and declined thereafter. Reported harvest for these three units showed no significant trends from 1983 onward and contemporary densities for these three units were equivalent, above and below the respective initial densities reported for these units. Thus, there was no strong evidence for a net change in sheep density throughout WRST, even though there has been some variance within individual survey units.

Harvest data were reported by hunters and not trained biologists. The quality of the data rests on the assumptions that a) the hunters honestly reported the location and horn measurements and b) that hunters were well enough informed to record and report the data accurately. No studies are available on the accuracy or possible biases of hunter-reported data. In Fig. 1.9 there are some obvious mis-classifications of sex reported. Hunter-reported horn lengths and ages likely did not represent a random sample of sheep in any given survey unit. We would assume that sport hunters selected sheep with longer horns which would have minimized differences among survey units unless real differences in horn length occurred. We observed two units with significantly shorter horns than other units (Fig. 1.9). Overall mean horn length of reported harvested rams was not significantly different from that reported by Murphy and Dean (1978).

Historically, more trophy sheep came from WRST than elsewhere in Alaska (Heimer and Smith 1975, Murphy and Dean 1978); however, the average reported horn lengths of reported rams harvested from the Chitina area (survey units 23E&W), known for its large horned rams in the 1970's (Heimer and Smith 1975 and 1979, Murphy and Dean 1978, Batin 1989), were not significantly larger than other survey units during the period 1983-2001.

Approximately half of the variation in hunter-reported horn lengths was explained by reported ages of animals harvested (Fig. 1.9). Other possible sources of variation in horn residuals include 1) differences in habitat, 2) differences in genetics, and 3) mis-reporting by hunters (there are clearly some mis-identified ewes in Fig. 1.9). Horn dimensions have been repeatedly demonstrated to have phenotypic plasticity and to be positively correlated with range quality (Edwards 1956, Heimer and Smith 1975, Bunnell 1978, Hoefs and Nette 1982, Douglas and Leslie 1986, Hoefs and Nowlan 1997, Jorgenson *et al.* 1998). Horn growth period is determined by photoperiod and sex hormones and should, with the exception of the first year, be similar for all sheep at the same latitude providing they have access to similar quantity and quality forage (Hoefs and Nette 1982, Konig and Hoefs 1984). Thus, we might expect that survey units with larger horn residuals to have higher quantity and quality of forage for sheep than survey units with smaller horn residuals (Fig. 1.10).

Mean annual reported harvest decreased linearly from 1973-2002 (Fig. 1.10, Murphy and Dean 1978). This trend may be due to restrictions on hunting within the park and/or decreased hunter participation. As expected, survey units with significantly higher reported harvest rates occured mainly within the preserve (Fig. 1.8).

MANAGEMENT IMPLICATIONS

It is important that surveys continue to use existing, established survey units for comparison purposes. Ideally, to estimate WRST-wide population size, annual surveys would be conducted of a sample of survey units, without replication, until each unit had been surveyed and then the process would be repeated (Mark Udowitz *person. comm.*). However, realistically, there are pressures to emphasize certain units over others. In this case we recommend annual surveys of units 9, 11, 12, 14, 21, and 22, which have an extensive survey history, with additional surveying using the random non-replacement strategy. Continued sampling of units with extensive histories will facilitate investigations of among year variability. With areas of survey units now estimated (Table 1.3) biologists should use total densities rather than indices such as lamb:ewe ratios to monitor survey units. The lack of correspondence among survey units, GMUs, UCUs, and park/preserve boundaries make it unlikely that comparisons between harvest data and survey data will ever be clearly elucidated.

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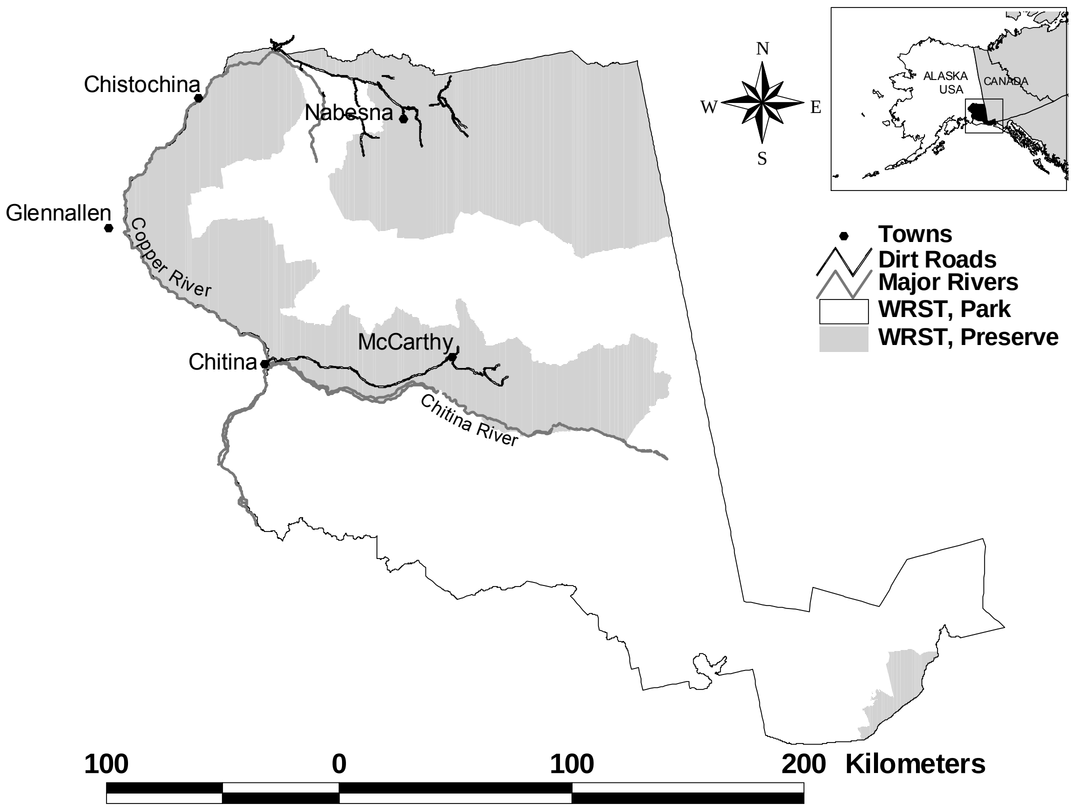

Figure 1.1. Location of Wrangell-St. Elias National Park and Preserve, Alaska.

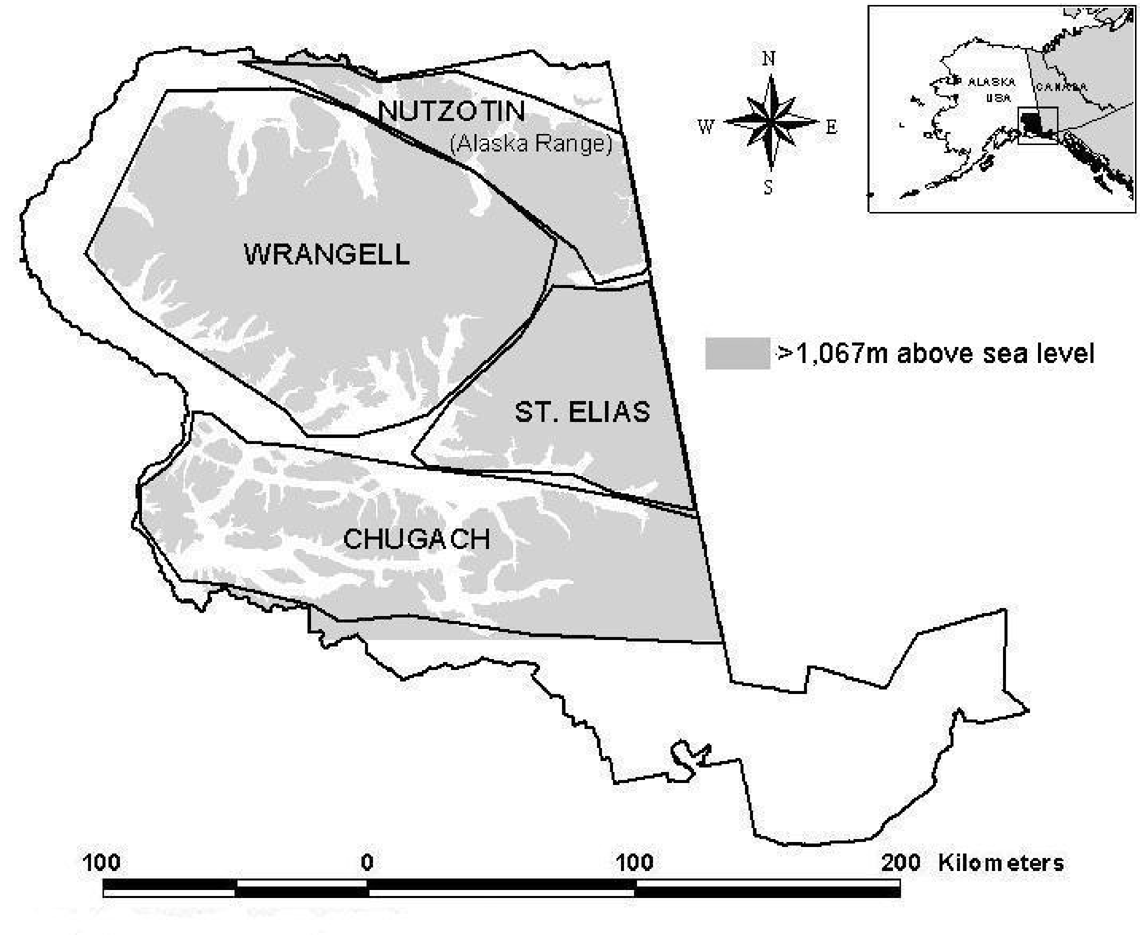

Figure 1.2. The four mountain ranges of Wrangell-St. Elias National Park and Preserve, Alaska. Shaded area represents >1,067m which is the approximate occurrence of treeline.

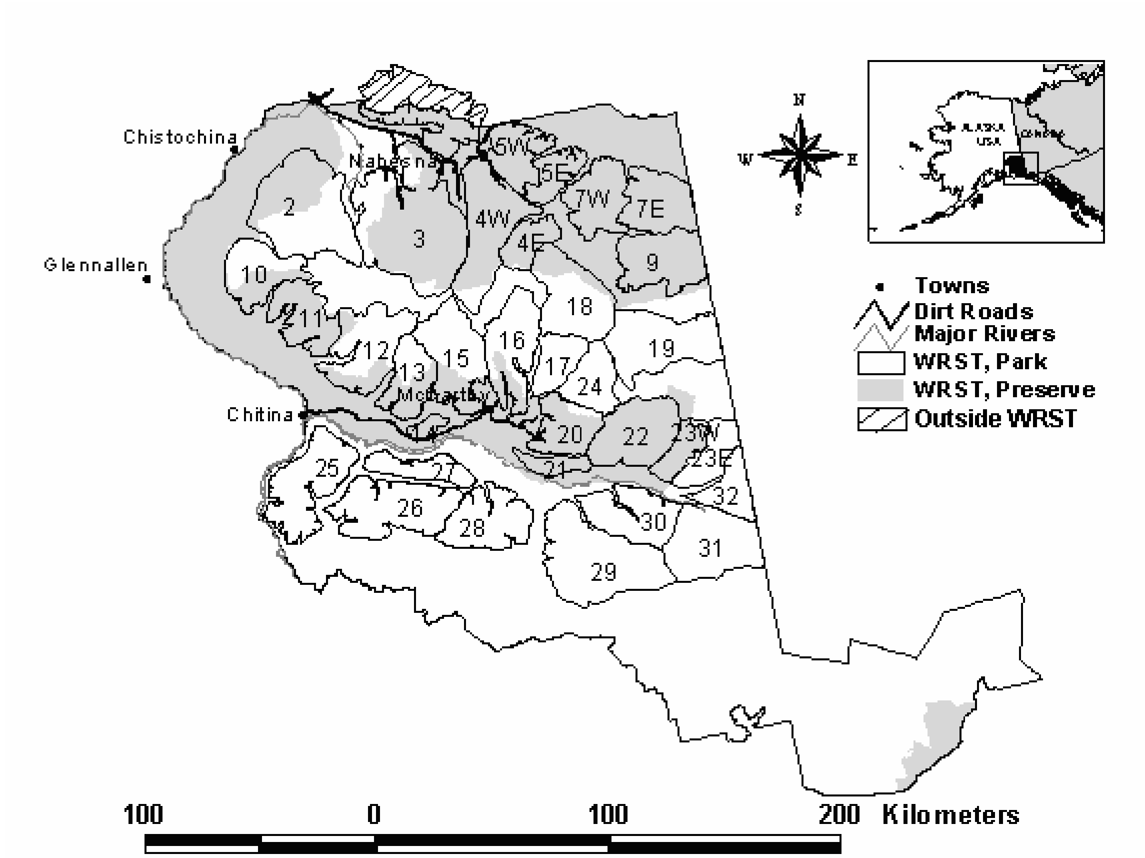

Figure 1.3. Mountain sheep (*Ovis dalli*) and goat (*Oreamnos americana*) aerial survey units, Wrangell-St. Elias National Park and Preserve, Alaska.

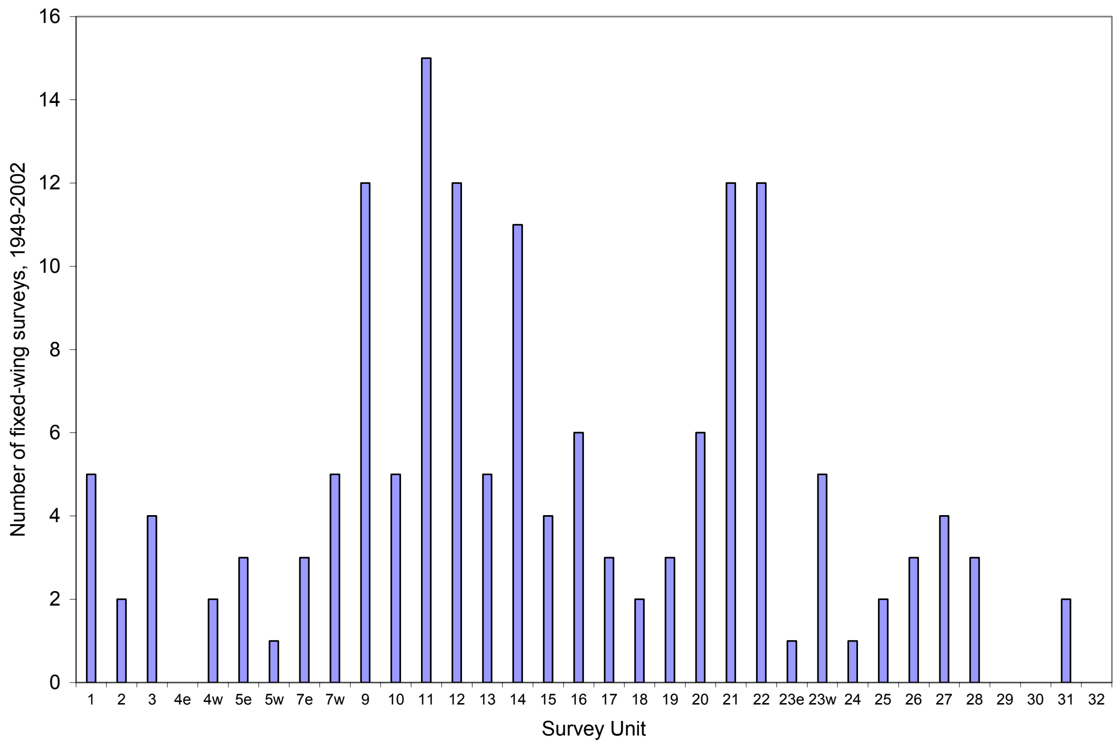

Figure 1.4. Total number of Dall's sheep (*Ovis dalli*) fixed-wing aerial surveys conducted per survey unit in Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Specific years surveyed are available in Appendix E.

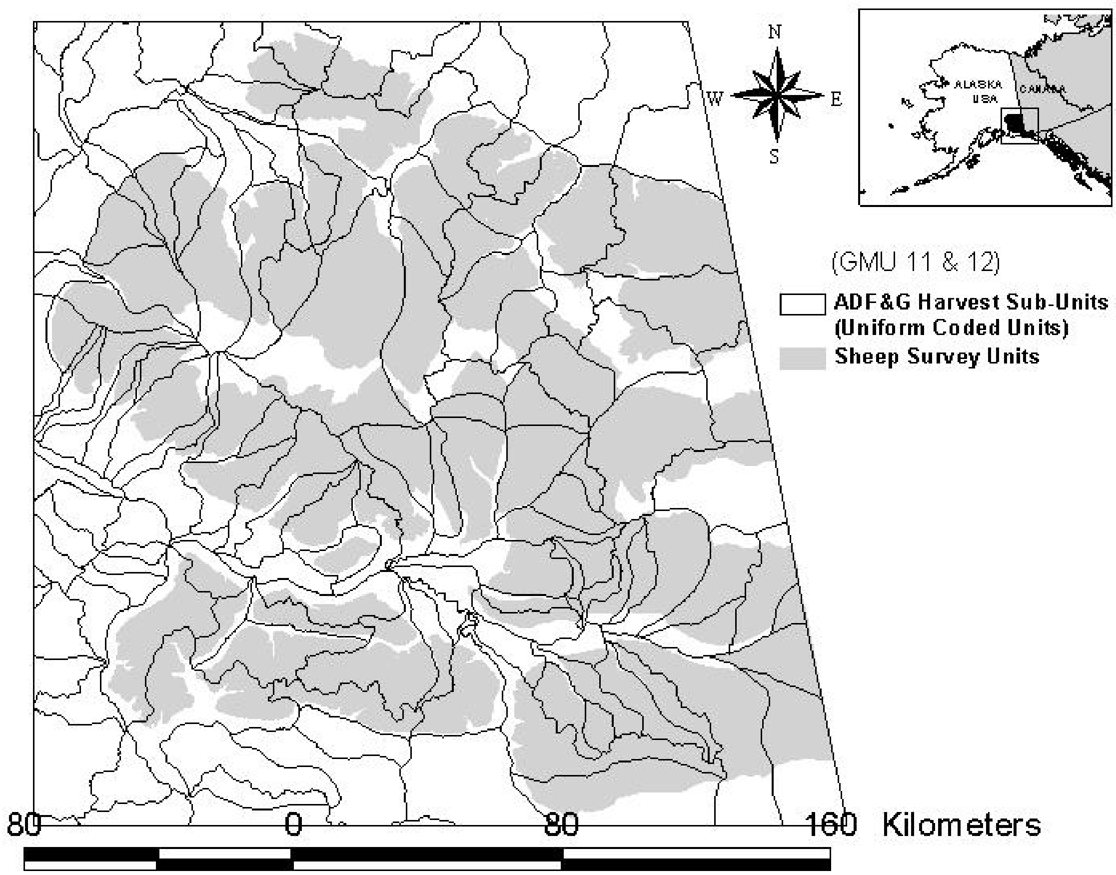

Figure 1.5. Alaska Department of Fish & Game harvest units (UCUs) overlaid on aerial survey units (SUs, in gray) in Wrangell-St. Elias National Park and Preserve, Alaska.

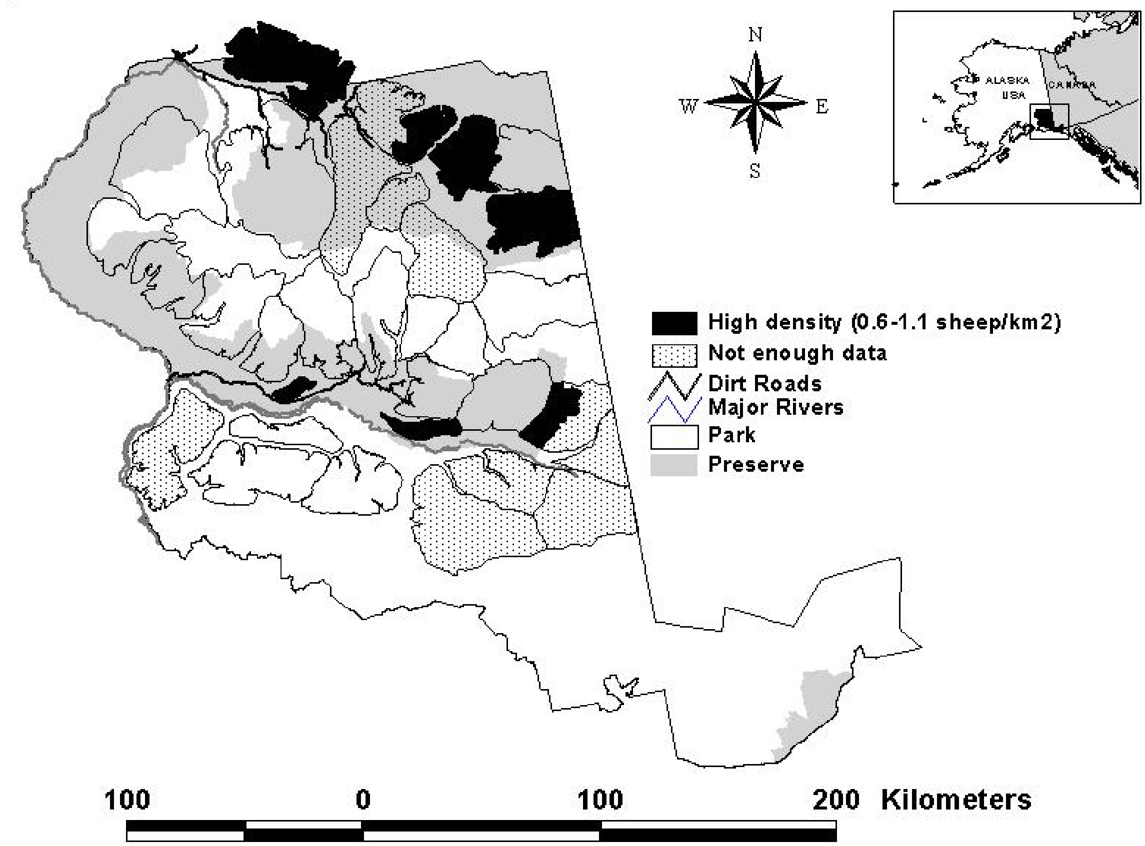

Figure 1.6. Relative density of adult Dall's sheep in aerial survey units, Wrangell-St. Elias National Park and Preserve, Alaska. Density (adult sheep/km2) data from fixed-wing aerial surveys, 1967-2002.

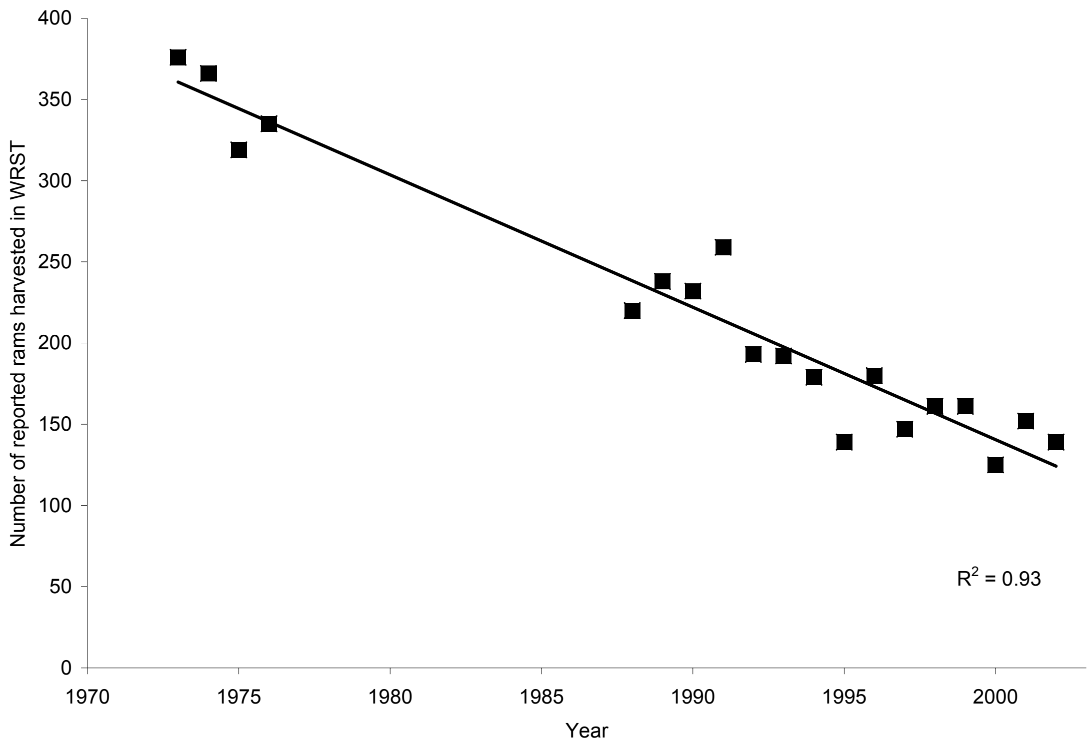

Figure 1.7. Number of hunter-reported Dall's sheep rams harvested in Wrangell-St. Elias National Park and Preserve, Alaska, 1973-2002. Harvests in the 1970's are from Murphy and Dean (1978). Both sport and subsistence hunted rams are included in totals.

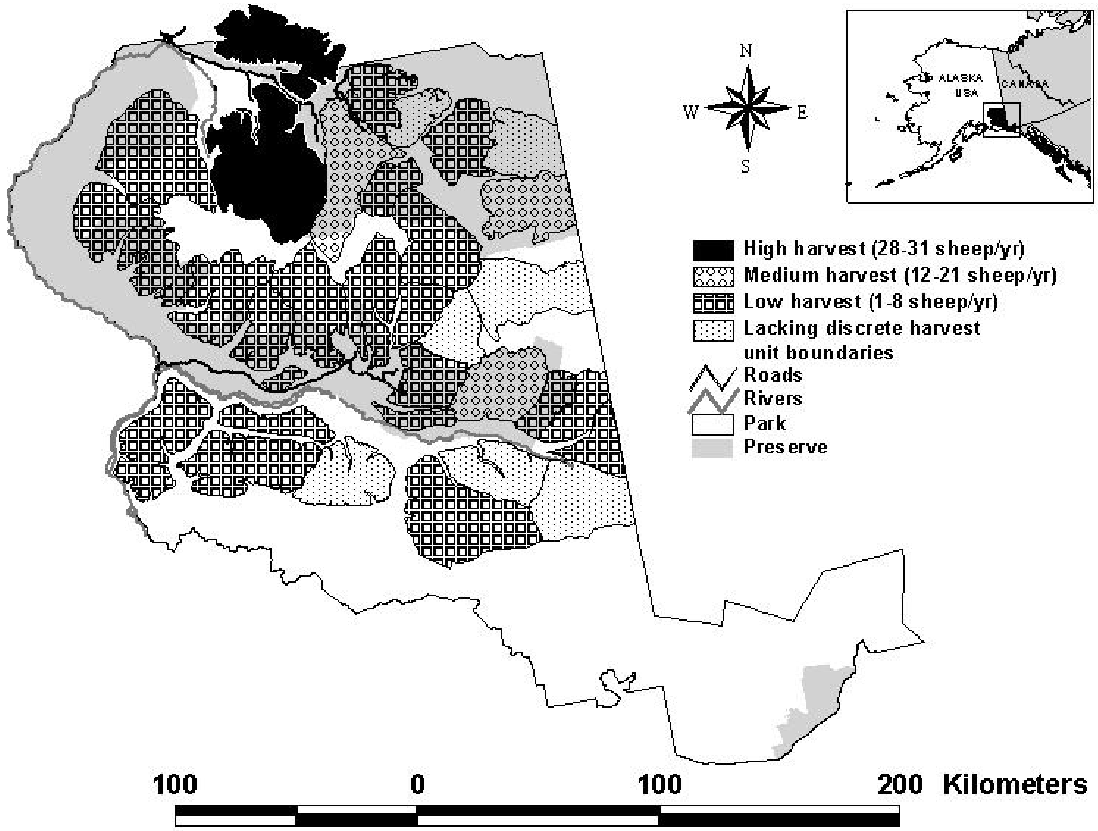

Figure 1.8. Relative level of hunter-reported harvest of Dall's sheep in aerial survey units, Wrangell-St. Elias National Park and Preserve, Alaska. Harvest data (sheep/year) are from hunter reports, 1983-2002.

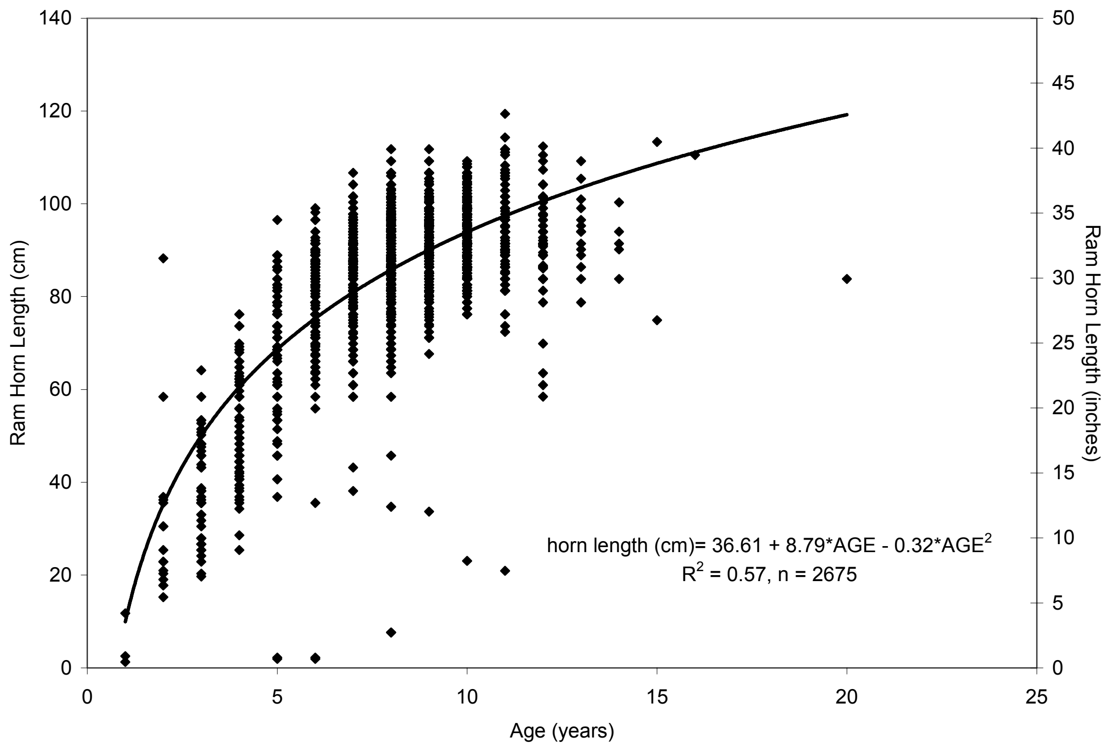

Figure 1.9. Horn length in relationship to age of reported rams harvested in Wrangell-St. Elias National Park and Preserve, Alaska. Both length and age were reported to Alaska Department of Fish and Game by hunters, 1983-2002.

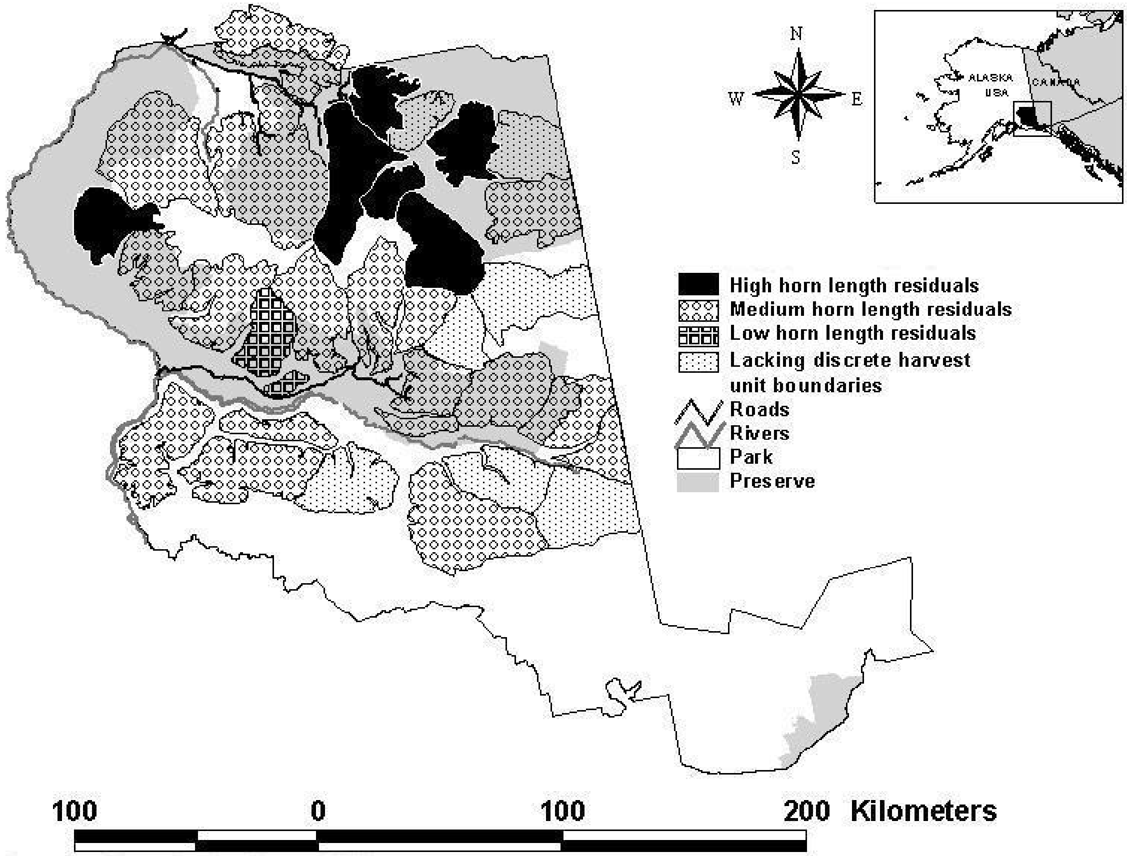

Figure 1.10. Relative mean horn length residuals from the regression of length on age in Dall's sheep in aerial survey units, Wrangell-St. Elias National Park and Preserve, Alaska. Horn lengths and ages are from hunter reports, 1983-2002.

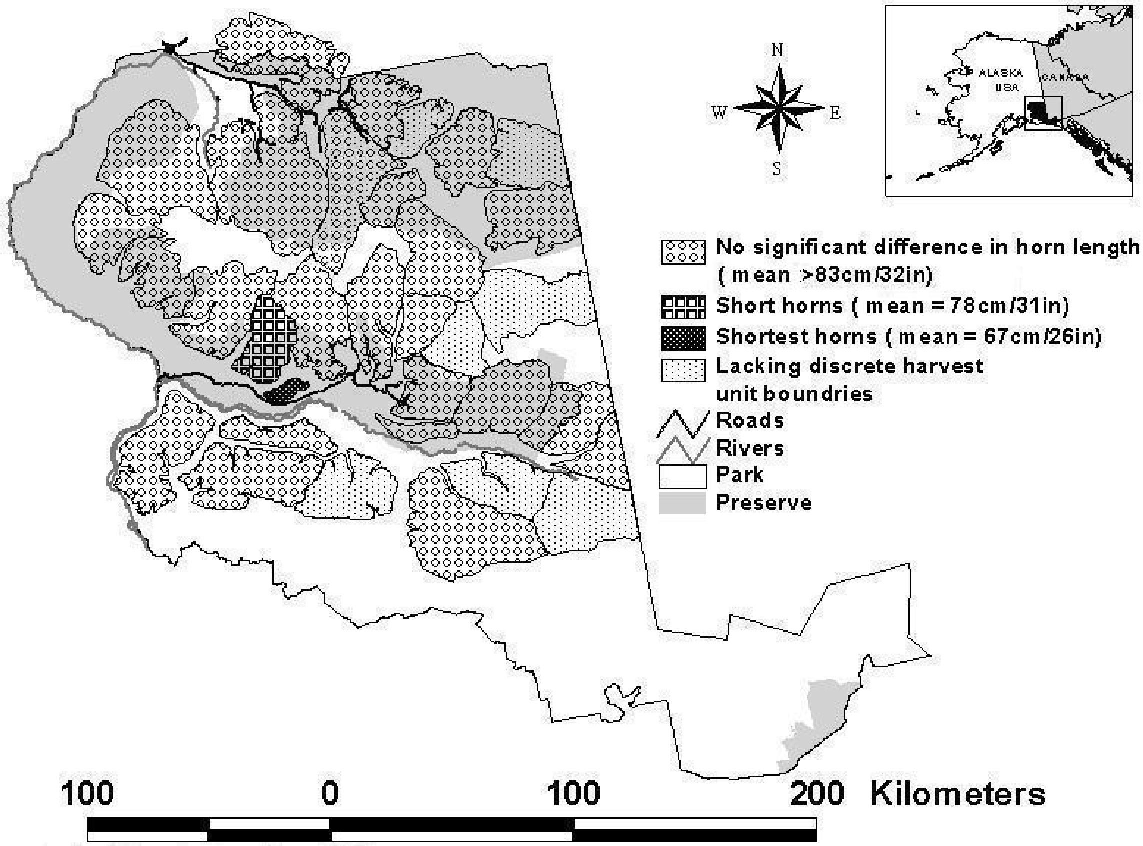

Figure 1.11. Relative hunter-reported horn lengths of Dall's sheep in aerial survey units, Wrangell-St. Elias National Park and Preserve, Alaska. Horn lengths are from hunter-reported harvest, 1983-2002.

Table 1.1. Fixed-wing aerial survey data for Dall's sheep, Wrangell-St. Elias National Park and Preserve, Alaska, 1949- 2002. (*Continued next page*)

		Density (Sheep/km2)				Lambs: 100 Ewes			
SU[a]	Range of years[b]	N[c]	$\bar{X}$[d]		SE	N[c]	$\bar{X}$[d]		SE
1	1971-2002	5	0.96	e	0.09	5	27		5.53
2	1973-2002	2	0.14	f	0.01	2	30	f	6.65
3	1973-1998	4	0.49		0.15	3	20		8.53
4E		0				0		f	
4W	1973-1998	2	0.37	f	0.18	2	24	f	6.48
5E	1974-2001	3	0.95	e	0.10	1	13	f	
5W	2001	1	0.75	f		1	21	f	
7E	1974-2001	3	0.53		0.22	3	19		7.28
7W	1974-1999	5	0.69	e, g	0.07	4	34		2.45
9	1949-2002	12	0.81	e	0.08	9	37		2.65
10	1973-1992	5	0.20		0.05	3	31		12.25
11	1973-2002	16	0.48		0.05	16	27		1.76
12	1967-2001	12	0.42		0.05	11	23		2.40
13	1984-1999	5	0.52		0.08	4	25		2.87
14	1950-2002	11	1.10	e	0.15	9	32		4.92
15	1973-1999	4	0.12		0.03	4	29		2.61
16	1968-1992	6	0.25		0.03	5	38		6.55
17	1973-1983	3	0.61		0.06	3	20		4.49
18	1968-1983	2	0.29	f	0.04	2	23	f	4.10
19	1968-1993	3	0.09		0.03	3	28		13.54
20	1970-2002	6	0.29	g	0.02	6	34		3.64
21	1970-2002	12	1.11	e	0.09	10	30		4.46
22	1970-2001	12	0.23		0.02	11	25		3.61
23E	1983	1	0.16	f		1	27	f	
23W	1980-1999	5	0.79	e	0.04	5	31		1.76
24	1983	1	0.18	f		1	41	f	

Table 1.1. *Continued.* Fixed-wing aerial survey data for Dall's sheep, Wrangell-St. Elias National Park and Preserve, Alaska, 1949- 2002.

		Density (Sheep/km2)			Lambs: 100 Ewes		
SU[a]	Range of years[b]	N[c]	$\bar{X}$[d]	SE	N[c]	$\bar{X}$[d]	SE
25	1973-1983	2	0.05 [f]	0.01	1	32 [f]	
26	1973-2002	3	0.00	0.00	0	[h]	
27	1973-1991	4	0.24 [l]	0.04	2	13 [f]	4.72
28	1973-1984	3	0.18 [j]	0.18	0	[j]	
29		0	[f]		0	[f]	
30		0	[f]		0	[f]	
31	1990-1991	2	0.02 [f]	0.00	1	33 [h]	
32		0	[f]		0	[f]	
mean	1949-2002	155	0.53	0.03	128	28	1.00

a) Survey unit identification code
b) Range of years surveyed. Specific years can be found in Appendix E.
c) Number of years surveyed
d) Mean
e) Significantly higher ($p < 0.001$) than all other survey units
f) Insufficient data to conduct test (< 3 aerial census surveys)
g) Statistically significant increase
h) Ewes or lambs were not identified separately from others
i) Statistically significant decrease
j) No sheep observations recorded

Table 1.2. Hunter-reported harvest of Dall's sheep, Wrangell-St. Elias National Park and Preserve, Alaska, 1983-2002. (*Continued next page*)

	Ewes			Rams								Unknown		
	Harvest			Harvest			Horn Dimensions					Harvest		
SU[a]	N	$\bar{X}$[b]	SE[c]	N	$\bar{X}$[b]	SE[c]	N	$\bar{X}$[b] Length (cm)	SE[c]	$\bar{X}$[b] Basal Circ. (cm)[d]	SE[c]	N	$\bar{X}$[b]	SE[c]
1	38	4	0.74	461	31 [e]	3.03	453	83.29 [f]	0.64	12.6	0.07	144	14	4.43
2	1	1		24	2	0.35	24	87.93 [f]	1.84	12.17	0.39	8	2	0.41
3	11	2	0.20	419	28 [e]	2.38	410	83.85 [f]	0.61	12.59	0.10	156	16	4.82
4E		[g]		69	5	1.29	69	89.27 [h]	0.62	12.79	0.19	15	4	1.49
4W		[g]		322	21 [i,j]	2.13	320	89.03 [h]	0.49	13.03	0.10	112	12	3.93
5E		[g]			[g]			[g]					[g]	
5W		[g]		66	4	0.66	65	87.86 [h]	1.23	13.24	0.10	40	8	1.82
7E		[g]			[g]			[g]					[g]	
7W		[g]		60	4	0.51	59	87.38 [h]	0.83	12.99	0.11	21	4	0.58
9		[g]		220	15 [i,j]	2.01	219	85.43 [f]	0.5	12.92	0.05	113	13	4.24
10	1	1		22	2	0.3	22	85.15 [h]	2.11	13.09	0.20	15	4	0.75
11	2	2		79	5	0.64	78	84.06 [f]	1.75	12.86	0.18	42	6	1.56
12	5	2	0.67	86	6	0.77	83	86.28 [f]	1.73	13.01	0.18	30	4	1.27
13	19	2	0.60	113	8	0.88	111	77.97 [k,l]	1.78	12.26	0.17	41	6	1.26
14	55	5	1.27	112	7	1.32	108	66.77 [k,m]	2.27	11.06	0.28	25	4	0.87
15	5	1	0.25	86	6	0.68	84	85.44 [f]	1.78	12.65	0.25	25	3	0.69
16	6	2	0.29	50	4	0.63	48	84.62 [f]	3.31	12.6	0.26	21	3	0.82
17		[g]		12	2	0.19	12	97.98 [f]	3.54	13.34	0.12	3	2	0.50

Table 1.2. *Continued.* Hunter-reported harvest of Dall's sheep, Wrangell-St. Elias National Park and Preserve, Alaska, 1983-2002. *(Continued next page)*

	Ewes			Rams								Unknown		
	Harvest			Harvest			Horn Dimensions					Harvest		
SU[a]	N	$\bar{X}$[b]	SE[c]	N	$\bar{X}$[b]	SE[c]	N	$\bar{X}$[b] Length (cm)	SE[c]	$\bar{X}$[b] Basal Circ. (cm)[d]	SE[c]	N	$\bar{X}$[b]	SE[c]
18		[g]		65	5	1.44	64	88.77[h]	1.24	13.29	0.10	12	2	0.52
19		[g]			[g]			[g]						
20	9	2	0.37	123	8	0.78	122	83.75[f]	1.65	12.5	0.18	28	2	0.51
21	3	3		78	5	0.64	77	93.04[f]	0.54	13.72	0.33	36	4	1.20
22	10	2	0.33	180	12[i]	1.1	177	89.19[f]	1.33	13.48	0.13	67	7	2.39
23E		[g]		6	2[n]	0.29	6	100.38[f]	2.42	13.75	0.28	1	1	
23W		[g]		36	3	0.54	36	90.7[f]	2.3	13.45	0.21	6	2	0.29
24		[g]		1	1		1	91.44[f]		12.75				
25	1	1		4	1		4	89.7[f]	6.24	13.56	0.39	7	4	2.50
26		[g]		4	1		4	102.87[f]	2.43	13.91	0.32			
27	9	2	0.37	13	2	0.33	13	90.2[f]	5.23	13.55	0.41	4	4	
28		[g]			[g]			[g]				2	2	
29		[g]		1	1		1	99.06[f]		14.00[i]				
30		[g]			[g]			[g]						
31		[g]			[g]			[g]						
32		[g]		5	2	0.26	5	96.27[f]	4.89	13.9	0.40	1	1	

Table 1.2. *Continued.* Hunter-reported harvest of Dall's sheep, Wrangell-St. Elias National Park and Preserve, Alaska, 1983-2002.

a) Survey unit identification code
b) Mean
c) Standard error
d) Basal circumference of horn
e) Significantly larger ($p < 0.001$) than all other SUs with sufficient data to conduct test
f) Significantly higher ($p < 0.001$) growth rate than those denoted with "k" but significantly lower growth rate than those denoted with "h" using age based residuals
g) Insufficient data to test
h) Significantly higher ($p < 0.001$) growth rate than all other survey units using age based residuals
i) Significantly higher ($p < 0.001$) than all other survey units except those denoted by "e"
j) Statistically significant decline
k) Significantly lower growth rate than those all other survey units using age based residuals
l) Significantly shorter than all other survey units except those denoted by "m"
m) Significantly shorter than all other survey units
n) Statistically significant increase

Table 1.3. Summary of Dall's sheep and mountain goat aerial survey unit areas within Wrangell-St. Elias National Park and Preserve, Alaska.

SU[a]	AREA (km^2)	
	PLANAR[b]	SURFACE[c]
15	940.87	1052.02
22	912.13	1072.21
12	952.39	1083.69
18	1009.01	1105.87
14	100.53	114.65
25	1003.09	1150.21
31	1054.00	1190.71
19	1079.73	1217.22
26	1075.31	1249.61
01	1158.30	1292.30
04W	1149.05	1292.44
02	1563.03	1662.41
29	1515.34	1697.06
21	201.61	220.70
03	2153.75	2361.96
23W	319.80	388.11
04E	359.84	397.16
05E	366.08	429.21
27	409.14	452.92
32	417.96	467.34
17	428.83	481.45
23E	452.08	544.30
24	517.85	598.44
05W	553.05	648.31
20	572.75	661.67
13	569.41	670.79
11	635.18	688.22
10	683.40	726.23
07W	691.04	786.96
07E	721.18	800.31
30	776.26	882.80
09	843.24	895.98
28	799.76	906.73
16	864.02	964.24

a) Survey unit identification code sorted ascending by area
b) Planar area
c) Surface area (estimated using 60m digital elevation models)

CHAPTER II.

RELATIONSHIPS AMONG POPULATION AND HABITAT CHARACTERISTICS FOR DALL'S SHEEP IN WRANGELL ST. ELIAS NATIONAL PARK AND PRESERVE, ALASKA[1]

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Abstract: The relationships among large-scale habitat attributes and population characteristics have not been estimated for Dall's sheep. A large scale study on desert bighorn sheep (McKinney *et al.* 2003) found population sizes to be positively correlated with measures of escape terrain, with escape terrain defined as slopes >60% with a 150m buffer of >40% slopes where sheep were presumed to avoid predators. We used multiple regression to estimate the relationships among population characteristics (density, reported harvest, and horn length of harvested rams) and habitat characteristics (attributes of escape terrain, terrain

[1]This chapter will be submitted to the Journal of Wildlife Management for publication

ruggedness, % south and west facing slopes, and relative greenness (normalized difference vegetation index, NDVI) for aerial survey units in Wrangell-St. Elias National Park and Preserve (WRST), Alaska using 1967-2002 aerial survey data and 1983-2002 records. We standardized all variables within units in relation to the WRST mean and evaluated all 1, 2, and 3 variable models using Akaike's Information Criterion for small sample sizes (AICc) for model selection. The best models for all estimates of sheep density (adult, lamb, and total) showed a positive correlation with median NDVI and terrain ruggedness. The weight of evidence was greatest for adult density and least for lamb density. Escape terrain, while in the top 10 models, was not significant. Fifty percent of horn length was explained by age. There was no one clear explanatory habitat model for horn growth (horn length adjusted for age) or reported harvest. The best model for density explained approximately half of the variation for Dall's sheep in Wrangell-St. Elias. Other possible sources of variance in density may include predation, snow cover, wind scouring in relation to snow cover, and differences in climatic zones.

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Key Words: aerial surveys, AIC, Alaska, Dall's sheep, density, escape terrain, forage, GIS, habitat, harvest, horn length, morphology, NDVI, *Ovis dalli*, terrain ruggedness, Wrangell-St. Elias National Park and Preserve, WRST

Dall's sheep (*Ovis dalli dalli*) only occur in North America. They are found in Alaska, the Yukon Territory, and northern British Columbia (Bowyer and Leslie 1992, Demarchi and Hartwig 2004). Historically, Dall's sheep habitats and ranges have remained relatively unchanged (Demarchi and Hartwig 2004). Small-scale studies found that Dall's sheep selected cliff faces for presumed predator avoidance (Whitten 1975, Frid 1997) with >51% slope considered to be "escape terrain" (Demarchi and Hartwig 2004). Escape terrain for bighorn sheep has been variously described as precipitous slopes where sheep may find refuge from predators (Berger 1991, Smith *et al.* 1991, Tilton and Willard 1982, Wakelyn 1987, 1987, Zeigenfuss *et al.* 2000, Alvarez-Cardenas *et al.* 2001, McKinney *et al.* 2003). Maternal Dall's sheep selected sites with forage and steep terrain while avoiding areas with deep snow (Whitten 1975, Rachlow and Bowyer 1998). Hoefs and Cowan (1979) speculated that forage production regulated Dall's sheep populations while Whitten (1975) found that sheep selected habitats with high forage quality. Snow depth and wind scouring may limit sheep populations (Geist 1971, Heimer et al. 1994) but adequate data to address this are currently not available.

Studies of closely related bighorn sheep (*Ovis canadensis,* Geist 1971 and 1974, Bowyer and Leslie 1992) found positive correlations between population size and good visibility and low vegetation coverage (Wakelyn 1987, Reisenhoover and Bailey 1988, Alvares-Cardenas *et al.* 2001), a large elevational range (Herbert 1973, Shackleton 1973, Wakelyn 1987, Etchberger and Krausman 1999), and terrain ruggedness (Singer *et al.* 2000, Smith *et al.* 1991, Zeigenfuss *et al.* 2000). A desert bighorn (*Ovis canadensis weemsi*) population in Baja del Sur, Mexico selected south-east and northern aspects (Alvares-Cardenas *et al.* 2001), and a Rocky Mountain sheep population (*Ovis canadensis canadensis*) in northern Montana, USA selected east and south-eastern aspects (Tilton and Willard 1982)

McKinney *et al.* (2003) estimated associations among population characteristics and escape terrain attributes for desert bighorn sheep (*Ovis canadensis nelsoni*) using linear regression models. They defined escape terrain as slopes ≥60% with a 150m buffer of slopes ≥40%. They inventoried landscapes of ≥40% slope for terrain ruggedness and attributes of escape terrain that included mean patch size, number of patches, patch density, percent of landscape, and perimeter-to-area ratios of patches. Ewe and lamb counts were found to be positively correlated with number of escape terrain patches, mean escape terrain patch size, and % of escape terrain in landscapes. Sheep densities were independent of the patch size of escape terrain.

To our knowledge, no large-scale quantitative habitat assessment for Dall's sheep has been conducted. Currently managers rely on variable expert opinion and information on other mountain sheep species to evaluate Dall's sheep habitat. Because most Dall's sheep range is remote, it can be prohibitively expensive to monitor population density and composition for all sheep ranges. An objective, quantitative, and large-scale method of assessing population characteristics (i.e. density, lamb:ewe ratios, reported harvest, and horn length of harvested rams) in relation to habitat would facilitate ranking of habitat quality and provide managers with population expectations. Our purpose was to estimate the relationships among sheep population characteristics (density, reported harvest, and horn length of harvested rams) and habitat attributes of sheep survey units in Wrangell-St. Elias National Park and Preserve (WRST) using 1967-2002 aerial survey data and 1983-2002 harvest reports. In addition to the escape terrain attributes estimated by McKinney *et al.* (2003) we considered aspect, relative greenness, and two different estimates of terrain ruggedness.

STUDY AREA

Established in 1980, WRST, is the largest unit it the U.S. National Park system. At 5,341,850 hectares, it is approximately 6 times the size of Yellowstone National Park (Fig. 2.1). It encompasses three climate zones: maritime, transitional, and interior (National Park Service 1998). The park and preserve contain portions of four mountain ranges (Alaska, St. Elias, Wrangell, and Chugach), the Gulf of Alaska coastline, the entire eastern half of the Copper River drainage, and the drainages of the Nabesna, Chisana and White Rivers (National Park Service 2004a) and is home to 25-35% of all Alaskan Dall's sheep

(Heimer and Smith 1975; Batin 1989). Along with adjacent Kluane National Park in the Yukon Territory, Glacier Bay National Park and Preserve in Alaska, and Tatshenshini-Alsek Park in British Columbia, WRST constitutes an 8 million hectare World Heritage Site (designated in 1979), the world's largest internationally protected area (National Park Service 1986).

The three climatic zones that occur in WRST are associated with mountain ranges: maritime (Chugach and St. Elias), transitional (Wrangell), and continental (the Nutzotin mountains of the Alaska range, National Park Service 1986). Areas within the maritime climatic zone receive large amounts of winter precipitation, while areas entirely within the interior continental climatic zone are characterized by relatively long, cold, and dry winters (National Park Service 2004). Glennallen, located in the interior continental zone, has a mean annual precipitation of 26 cm with mean summer (Jun-Sept) temperatures of 11°C and mean winter (Nov-Mar) temperature of -14°C (Alaska Climate Research Center 2004). Yakutat, located in the maritime zone, receives a mean of 384 cm of precipitation annually (National Park Service 2004) with mean temperatures of 10°C in summer and -0.6°C in winter (Alaska Climate Research Center 2004). Areas within the transitional zone receive more snowfall on southern slopes and are drier on the northern slopes (National Park Service 2004). Treeline throughout the park generally occurs between 1,067-1,219 m in elevation (Denton and Karlén 1977, National Park Service 1986) with the exception of the

Chugach range where treeline is lower, at 762-914 m above sea level (National Park Service 1986).

Politically, WRST is composed of park and preserve areas (Fig. 2.1). The preserve areas were delineated on the basis of traditional use and proximity to private in-holdings and villages. Both sport and subsistence hunting are allowed within the preserve, with only subsistence hunting allowed in the park (Alaska National Interest Lands Conservation Act 5 sec. 8-03, 805 and 815, 1980).

There are 34 survey units within WRST (Fig. 2.1). These survey units are primarily above 915 m in elevation and exclude heavily glaciated areas. They range from approximately 104-2234 km^2 in size (surface area estimated using a 60 m Digital Elevation Model, DEM). We inventoried all 34 survey units for habitat characteristics, but sheep survey data were only available for 23 and reported harvest for 28 of these units.

METHODS

Alaska Department of Fish and Game (ADF&G) and WRST biologists have censused sheep and mountain goat (*Oreamnos americana*) survey units sporadically since 1949. We used data from 1967-2002 for our analyses. Surveys were performed using fixed-wing aircraft and were primarily conducted between 14 June and 8 August 1967-2002 with the exception of 2 surveys in 1967 which were flown 30 November and 1 December. Winter surveys reported similar numbers to surveys conducted earlier in the year and were included in analyses (survey units are large enough to encompass both winter and summer ranges). Most surveys included classifications of animals to sex and class of curl size of horns. Classification of horn curls from aircraft is difficult and varies with the experience of the observer (Strickland 1992). We did not feel confident enough in the horn curl classifications to use those data.

We estimated densities (total sheep, adult sheep, and lambs) and lamb:ewe ratios (LE) of survey units with $\geq$3 surveys using surface area estimated from a 60m DEMs (Jenness 2004a). Densities were a more consistent measure for comparison than counts of sheep because survey unit size varied (Eberhardt 1978). Included in our model was one survey unit (27) where sheep have never been detected (n = 3 surveys). Pearce and Ferrier (2001) argue that habitat models are stronger if areas where the species of interest is absent, but that are otherwise similar, are also included in the study.

Mean reported ram harvest, horn length and horn basal circumference of harvested rams for survey units were estimated using spatially explicit harvest records (both sport and subsistence) reported by hunters to ADF&G in 1983-2002 (n = 2675 rams, 15 years). We also estimated horn length residuals from the regression of length on age (hereafter referred to as horn residuals) from reported harvests for survey units (Chapter 1, Fig. 1.9). No spatial data for reported harvests were available prior to 1983 (Brian Lieb, *person. comm.*). Harvest records are from Game Management Units (GMUs) 11 and 12 and include data from both subsistence (legal in both park and preserve) and sport (legal only in preserve) harvests (ADF&G historical records). Harvest regulations differed among GMUs as to the curl size of rams that were allowed to be taken. Survey units did not always clearly fall into park or preserve or one GMU. It was not possible to differentiate sport from subsistence harvests from the records.

Habitat characteristics were inventoried using Geographic Information Systems (GIS) for each survey unit. Physical terrain was described in terms of elevation range, aspect, slope, and terrain ruggedness for each survey unit with existing National Park Service GIS themes using 60m DEMs obtained from the Northern Field Office of the Bureau of Land Management. Escape terrain was estimated after McKinney *et al.* (2003) as areas with slope $\geq$60% plus a 150 meter buffer of $\geq$40% slope. Mean patch size, number of patches, patch density, percent of survey unit, and perimeter-to-area ratio of patches of escape terrain within survey units were estimated using GIS and Fragstats® (McGarigal *et al.* 2004). South (120-210°) and west (210-300°) facing slopes were estimated as percent of the survey unit.

Terrain ruggedness has long been considered important for all mountain sheep although most evaluations of it have been qualitative (Geist 1971, Hansen 1980, Smith *et al.* 1991). Varying quantitative methods for estimating terrain ruggedness exist (Hobson 1972, Evans 1972, Holl 1982, Beasom 1983, Turner 1989, Heimer *et al.* 1994, Nellemann and Fry 1995). We used two methods described by Hobson (1972) and adapted for a GIS: 1) a surface to planar area ratio (Rug1) and 2) a vector dispersion technique combining both slope and aspect (Rug2). To estimate Rug1 we used Jenness Enterprises' Surface Tools extension for ArcView® (Jenness 2004b) for a grid based GIS. If surface and planar areas are the same Rug1=1. To estimate Rug2 we used a script developed by Sappington for desert bighorn sheep (*Ovis canadensis nelsoni,* Sappington *person. comm.* 2004).

Rug2 decomposed a 60m DEM into its x, y, and z components (latitude, longitude, and altitude) using standard trigonometric operators and the slope (α) and aspect (β) of the cell. A moving window was then used to calculate the magnitude of the resultant vector for a given neighborhood size. We used a window of 5 nearest neighbors (i.e. pixels, approximately 0.44km^2) which is far smaller than the maximum known 2-week home range of Dall's sheep in Alaska of 13km^2 (Lawler *et al.* 2004) using a terrain ruggedness script for ArcView® (M. Sappington, National Park Service, *pers. comm.*). This results in a ruggedness index with a range of 0-1, with 1 being the most rugged.

To estimate landcover and relative greenness, three Landsat Enhanced Thematic Mapper+ (TM) images (Landsat 7 satellite) were obtained from the USGS EROS Data Center in Sioux Falls, South Dakota for complete coverage of all survey units: September 10, 2001 (Scene ID: LE7064017000125350) , June 16, 2002 (Scene ID: LE706517000216750) and August 5, 2002 (Scene ID:

LE7063017000221750). Imagery was selected based on availability and minimal cloud cover.

We attempted to expand an existing 30m resolution landcover map (Pacific Meridian Resources 1997) using the satellite images for a supervised classification. In supervised classification, spectral signatures are developed from specified locations in the image which are used as training sites and are defined by the user (Verbyla and Kang-tsung 1997). We used the existing landcover classifications, where they overlapped the imagery, as our training sites. Classes were reduced to forested, glacier/ice, barren, vegetated (non-forested: forbs, gramminoids, shrubs), and water from 27 classes in the existing landcover map. Clouds and cloud shadow were removed from satellite imagery by setting their reflectance values to zero (SETNULL, ArcInfo®). Imagery was then georeferenced and converted to a stack of grids with one grid for each spectral band (8 total, IMAGEGRID, ArcInfo®). An ASCII file with all known landcover cells and overlaying TM imagery values was created for a signature file (SAMLESIG, ArcInfo®). The signature file was then used to classify each TM image (MLCLASSIFY, ArcInfo®). This was performed first with the June 2002 image which overlapped the existing landcover map. The resulting expansion was then used to repeat the procedure with the September 2001 image and then the August 2002 image. The three TM images were then stacked with June taking precedence over September and September taking precedence over

August and merged. The August image had the highest cloud cover of the three images. This resulted in landcover coverage for survey units: 10-17, 21-22, 25-27. For each of these survey units we estimated % vegetated (i.e. alpine tundra).

Relative greenness of survey units was estimated using median 30m resolution Normalized Difference Vegetation Index (NDVI) (Myneni *et al.*1998) derived from the same TM images used for the attempted landcover map expansion. NDVI is a reflectance based index defined as the ratio: [(near infra-red, NIR) – (visible red band, VIS)] / [(NIR) + (VIS)], where NIR is reflectance in the 0.76-0.90 μm (Band 4) and VIS is reflectance in the 0.63-0.69 μm (Band 3) wavelengths for TM imagery (Tarpley *et al.* 1984, Tucker *et al.* 1984). Chlorophyll present in vegetation absorbs more VIS radiation than NIR, resulting in NDVI > 0 (Shippert *et al.* 1995). The scale of NDVI ranges from -1 to 1 with negative values representing clouds, snow, water, and non-vegetated surfaces (Markon *et al.* 1995). Negative value pixels were set zero. NDVI values >0 are positively correlated with green plant biomass in non-forested areas (Markon *et al.* 1995, Shippert *et al.* 1995), net primary productivity (Hunt 1994, Paruelo *et al.* 1997) and provide comparison between similar habitats (Myneni *et al.* 1998).

NDVI was integer scaled (0-250) and classified to quarter standard deviations from the mean (i.e., 27 classes ranging from -13 to +13) for each image to minimize differences caused by having images from different time periods and different satellite platforms and then the median pixel value was estimated for each survey unit. All other habitat and population variables for survey units were standardized to quarter standard deviations of WRST means ([value-$\bar{x}$ for all survey units]/ SD) separately and expressed as continuous values to match the range of standardized values for NDVI.

We ran a Pearson's correlation on standardized habitat characteristics to identify and eliminate multicollinearity (Zar 1984) and to reduce the number of independent variables due to our small sample size (n = 23 survey units).

We estimated the relationships between habitat variables and 1) reported harvest, 2) sheep densities, 3) reported horn length of harvested rams, and 4) horn length residuals adjusted for age separately using multiple regression. We used Akaike's Information Criterion corrected for small sample sizes (AICc, Akaike 1973, Burnham and Anderson 1998, Anderson *et al.* 2000) to evaluate all 1, 2, and 3 variable multiple regression models, where models with lower AICc values were considered "best" and the relative strength of fit was estimated as the weight of evidence for the best model (w_i, Burnham and Anderson 2002). We restricted our analyses to all possible 3 independent variable models due to our small sample sizes of 23-28 survey units. SAS V.8 (SAS Institute 1990) was used for all statistical analyses. Alpha was set *a priori* at 0.05.

RESULTS

Expansion of the existing landcover map was unsuccessful. The expansion resulted in clearly erroneous classifications such as lakes on steep hillsides. This problem may have been the result of similar reflectance properties of non-vegetative surfaces and mountain shadow (Verbyla and Kang-tsung 1997). The August image, which contained the most cloud cover, contained most of the problem classifications.

Percent of a survey unit above treeline that was vegetated was strongly correlated with median standardized NDVI (Fig. 2.2). We had limited coverage of landcover and complete coverage of NDVI over survey units. Therefore we excluded landcover and included median NDVI as one of the independent variables for habitat modeling. This increased the number of survey units we could include in our analysis from 13 (limited by landcover map) to 23 for densities and to 28 for reported harvest and horn length of harvested rams. We also excluded escape terrain patch density, number of patches, and total km^2 of escape terrain since these were highly correlated with % escape terrain in (Fig. 2.3, a-c). We excluded RUG2 from analyses because, of the two ruggedness indices, RUG1 provided an estimate of terrain ruggedness at the survey unit level while RUG2 was a pixel based estimate more suitable when the exact locations of animals were known.

We did not use lamb:ewe ratios for habitat models as we found no statistically significant variation among survey units (Chapter 1, Table 1.1, ANOVA, $F_{29,76} = 2.14$, $P = 0.19$). Mean observed sheep densities varied significantly among survey units (Chapter 1, Table 1.1, ANOVA, $F_{30,87} = 1.32$, p <0.0001).

Summary statistics of habitat characteristics (independent variables) used in linear regression for Dall's sheep aerial survey units are presented in Table 2.1. Summary information on population characteristics for Dall's sheep aerial survey units were presented in Chapter I, Tables 1.1 and 1.3.

One and 3 variable models for densities had lower relative weights (w_i) than 2 variable models indicating that 3 variables may have over-fit our data (Table 2.2, Burnham and Anderson 2003). We only consider results from 1 and 2 variable models hereafter.

Mean total density was positively correlated with median NDVI and terrain ruggedness (n = 22, p = 0.001, Table 2.3). It was best predicted by the model (p < 0.0001): standardized mean density = [0.06 (SE = 0.68)] + [NDVI * 1.00 (SE = 0.23)] + [RUG1 * 0.42 (SE = 0.21)] where all variables were standardized to quarter standard deviations of WRST means. The "best" model for the individual cohorts, adults and lambs, was the same as for total densities (Table 2.2).

Habitat models were not significant for reported harvest (n = 19, $r^2 = 0.07$, p = 0.22) and there was no clear "best" model (Table 2.4). Approximately 50% of variation in reported horn length was explained by reported age (Chapter 1, Fig. 1.9, $r^2 = 0.56$). Horn length residuals were modeled with habitat variables to remove the effect of age as an explanatory variable. Habitat did not predict horn residuals nor was there a clear “best” model (Table 2.5, n = 18, $r^2 = 0.25$, p = 0.05) Two variable models were not significantly better than 1 variable models for reported harvest or horn length residuals.

We used our best density model to predict mean sheep densities for survey units that have been surveyed <3 years (Table 2.6).

DISCUSSION

Our models assumed linear relationships between population and habitat characteristics. Individual plots of habitat vs. population characteristics did not suggest the presence of non-linear relationships. The population characteristics modeled were based on mean estimates over a period of years due to inconsistent surveying of units. In order to increase our sample size and prevent frequently surveyed units from dominating our results we took mean densities of all years surveyed. Sheep populations are known to fluctuate from year to year (Whitten 1975), and it is likely that our models would not accurately predict any single year’s estimate of density or reported harvest.

Median NDVI consistently appeared in the top models for sheep density in WRST (Table 2.2). NDVI has been found to be positively correlated with green plant biomass in non-forested areas (Markon *et al.* 1995, Shippert *et al.* 1995) and net primary productivity (Hunt 1994, Paruelo *et al.* 1997). The estimates of NDVI from different image dates assumed that relative differences within scenes were preserved among and within years. Green biomass is a reflection of forage quantity available for Dall's sheep and has been shown to increase Dall's sheep survival rates, body condition, and growth rates of individuals and groups (Bunnell 1978, Hoefs and Cowen 1979, Hoefs 1984, Hoefs and Nowlan 1997). Alone, terrain ruggedness was insignificant. When added to NDVI, terrain ruggedness significantly improved the model (Table 2.3) for total sheep density.

Approximately half of horn length was explained by age (Chapter 1, Fig. 1.9). Horn residuals, based on reported horn lengths corrected for age, were not strongly predicted by any one model (Table 2.6). We would expect that habitat and genetic differences might explain additional variation in survey unit horn residuals (Edwards 1956; Heimer & Smith 1975; Bunnell 1978; Hoefs & Nette 1982; Douglas & Leslie 1986; Hoefs & Nowlan 1997; Jorgenson *et al.* 1998). It is possible that differences in horn length at age among survey units were a result of genetic differences, errors in hunter estimated data, or a biased hunter obtained sample of rams of harvestable size. This is confounded by the fact that both sport and subsistence harvested animals were reported and were not clearly separable and that hunters, given the chance, would likely select larger sheep which may minimize the differences among survey units.

Escape terrain (McKinney *et al.* 2003) did not predict density, reported harvest, or horn residuals. It appears that there is less escape terrain available to sheep in WRST than in McKinney *et al.*'s (2003) study. McKinney *et al.* (2003) estimated escape terrain for landscapes composed entirely of >40% slope while we estimated escape terrain for entire survey units (<65% of survey units had >40% slope). McKinney *et al*.'s landscapes (2003) had a mean of 41% escape terrain whereas <3% of any WRST survey unit was escape terrain (Table 2.1). Recent studies of bighorn sheep (*Ovis canadensis,* Berger 1991, Bleich 1996, 1999) indicate that escape terrain may not improve the survival rate of sheep threatened by predators.

Approximately half of the variance in density and reported harvest of Dall's sheep in WRST was explained by our habitat models. To our knowledge, these models were the first large-scale quantitative assessments of habitat for Dall's sheep and the first large-scale habitat assessments for mountain sheep to include forage-related variables. The predictive power of the density model (Table 2.4) could be tested in WRST by conducting at least 3 or more consecutive aerial surveys in survey units listed in Table 2.4. However, because the model only explained 50% of the variation in density the confidence limits were wide and the predictions may not be very accurate. We would expect the density model to be most relevant for neighboring Kluane National Park, Yukon Territory which has similar climatic and latitudinal influences to WRST, and possibly relevant for Denali National Park, Alaska which has high sheep densities similar to WRST (Singer 1984). We expect the model of density to be less relevant for the Brooks Range, Alaska which is at a higher latitude and in an arctic climate zone and where sheep are less dense (Singer 1984). Our model might be improved with the consideration of additional sources of variation such as the spatial heterogeneity of snow cover in winter, wind scouring in relation to snow, climate (maritime vs. interior), landcover, and predator risk. Currently, estimates of these additional variables are unobtainable.

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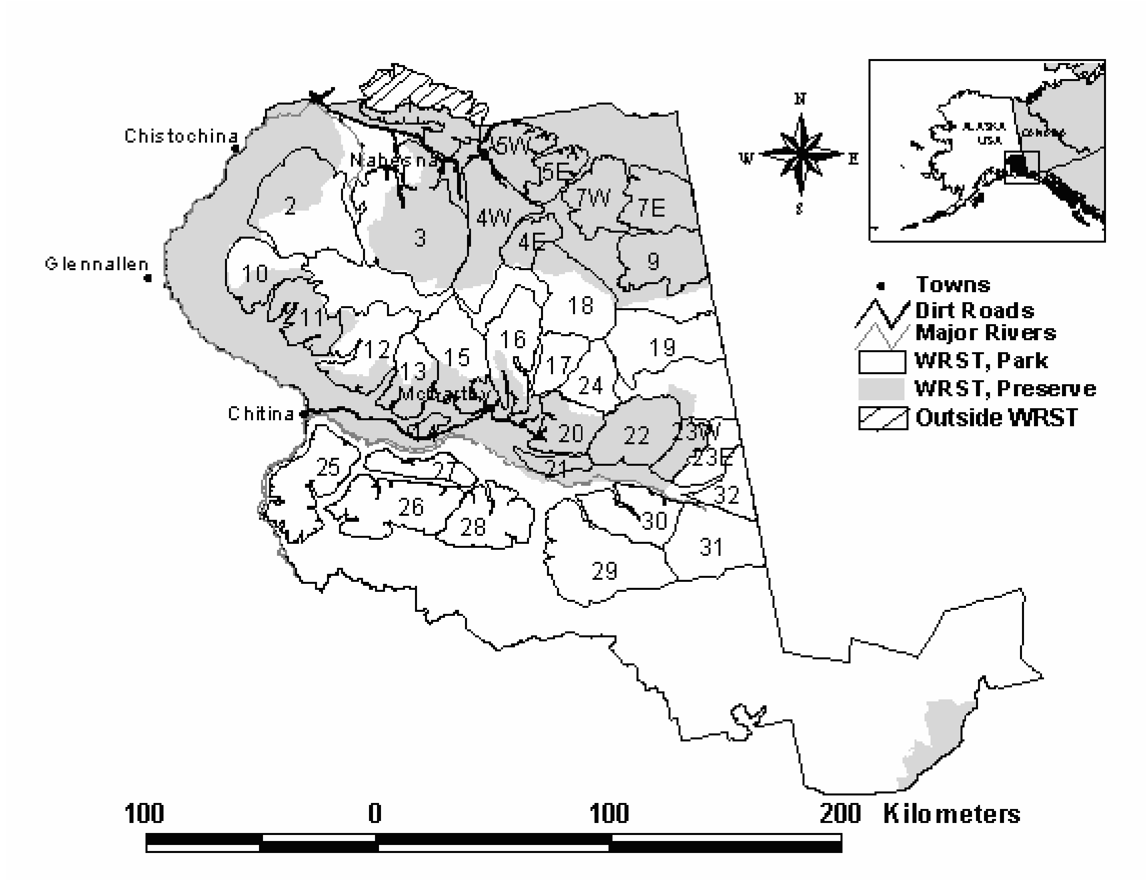


Figure 2.1. Location of Dall's sheep (*Ovis dalli*) and mountain goat (*Oreamnos americana*) survey units, Wrangell-St. Elias National Park and Preserve, Alaska.

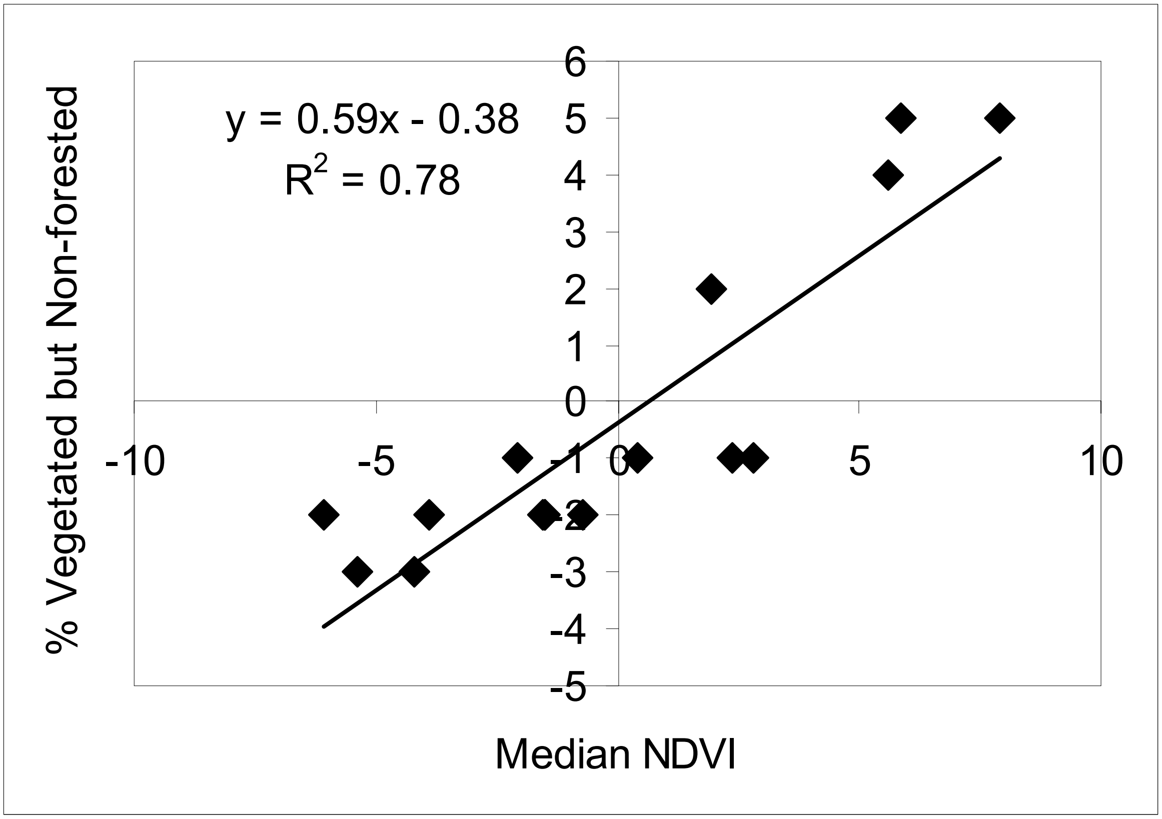
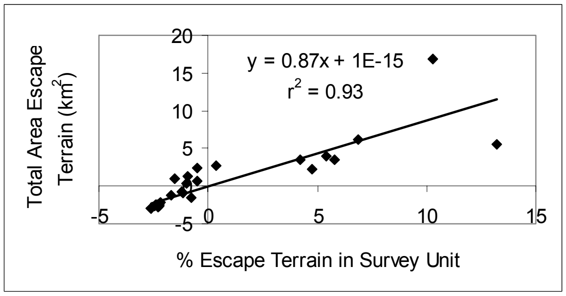
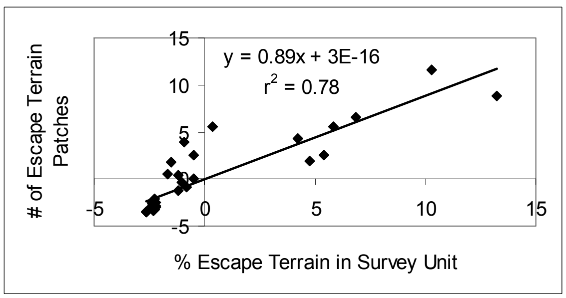


Figure 2.2. Correlation between standardized NDVI (normalized difference vegetation index) and standardized percent non-forested but vegetated (alpine tundra) landcover in 13 Dall's sheep survey units, Wrangell-St. Elias National Park and Preserve, Alaska. Correlation was based on a partial landcover map (Pacific Meridian Resources 1997) of WRST. NDVI was estimated from three satellite images: 10 Sept 2001, 16 Jun 2002, and 5 Aug 2002.

a)



b)



c)

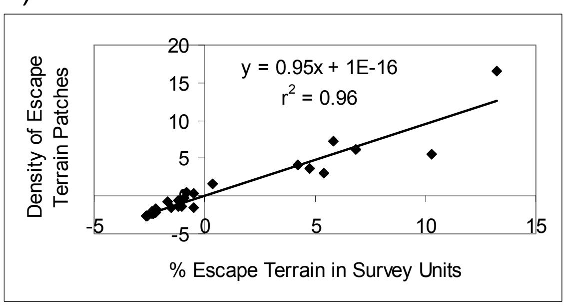


Figure 2.3. Correlated habitat variables estimated in Dall's sheep aerial survey units in Wrangell-St. Elias National Park and Preserve, Alaska. Escape terrain is defined after McKinney *et al.* (2003) as ≥60% slope buffered by 150m of ≥40% slope.

Table 2.1. Summary statistics of habitat characteristics in Dall's sheep aerial survey units in Wrangell-St. Elias National Park and Preserve, Alaska.
(Continued on following page)

SU[a]	P_VEG[b]	NDVI[c]	RUG1[d]	P_ESC[e]	PARA[f]	P_SOUTH[g]	P_WEST[h]
1		6	1.03	0.00	0.00	24.47	25.16
2		-3	1.03	0.28	159.08	16.23	27.95
3		-2	1.04	0.15	213.74	18.64	22.32
4e	35.76	-1	1.10	0.05	172.22	20.05	14.59
4w	26.43	-3	1.12	0.22	157.95	17.46	27.80
5e		-1	1.17	0.05	195.51	25.72	23.73
5w		-3	1.17	0.05	183.50	23.18	24.11
7e		1	1.03	0.00	0.00	28.31	20.66
7w		1	1.04	0.00	0.00	23.54	26.64
9		4	1.02	0.00	0.00	23.42	25.36
10	57.20	-1	1.02	0.03	192.13	21.59	36.79
11	55.29	-1	1.03	0.00	0.00	33.05	32.09
12	38.38	-2	1.05	0.05	192.92	29.67	27.90
13	38.11	-2	1.07	1.27	173.51	31.03	31.24
14	70.73	5	1.04	0.00	0.00	35.13	18.75
15	18.14	-2	1.05	0.19	232.12	28.77	20.44
16	27.74	-2	1.05	0.19	213.68	30.79	21.85
17	41.76	-2	1.05	0.98	171.18	26.40	27.81
18		-3	1.04	0.06	155.72	25.62	22.25
19		-3	1.04	0.03	174.98	19.24	24.07
20		-1	1.05	0.91	165.87	27.87	29.76
21	79.77	5	1.04	0.04	194.44	35.15	25.10
22		-3	1.07	1.72	171.99	37.47	27.68
23e		-3	1.07	1.12	293.60	18.32	30.37
23w		4	1.07	2.11	179.71	22.43	38.71
24	21.32	-3	1.07	1.07	254.24	18.32	30.37
25		-2	1.06	0.28	194.86	22.24	23.08
26		-1	1.06	0.12	204.51	23.05	26.52
27	69.53	4	1.04	0.00	0.00	29.66	20.13
28		2	1.05	0.04	200.96	24.32	26.70
29		-2	1.05	0.23	187.52	24.45	28.34
30		-3	1.03	0.01	203.70	16.09	27.16
31		-4	1.13	0.40	185.17	18.73	26.19
32		-3	1.12	0.24	181.11	28.78	29.06
Mean	44.63	6	1.06	0.35	153.12	24.98	26.20

Table 2.1. *Continued.* Summary statistics of habitat characteristics in Dall's sheep aerial survey units in Wrangell-St. Elias National Park and Preserve, Alaska.

a) Survey unit identification code
b) % non-forest vegetated from Pacific Meridian (1997) landcover map
c) Normalized difference vegetation index which estimates relative greenness from reflectance values in satellite imagery (Markon *et al.* 1995, Shippert *et al.* 1995). These values are standardized to the mean.
d) Terrain ruggedness estimated using a planar: surface area ratio with surface area estimated using a 60m DEM (Hobson 1972)
e) % escape terrain with escape terrain defined as >60% slope with a 150m buffer of >40% slope (McKinney *et al.* 2003)
f) Perimeter: area ratio of escape terrain patches with escape terrain defined as >60% slope with a 150m buffer of >40% slope (McKinney *et al.* 2003)
g) % south (120-210°) facing slope in survey units
h) % west (210-300°) facing slope in survey units

Table 2.2. Best 1, 2, and 3 independent variable models, based on AICc (Burnham & Anderson 1998), for sheep densities in Wrangell-St. Elias National Park and Preserve, Alaska. Densities were estimated from fixed-wing surveys flown1967-2002.

Dependent Variable	K[a]	MODEL			r^2	w_i[b]
Adult density	2	NDVI[c]			0.39	0.18
Adult density	3	NDVI	RUG1[d]		0.51	0.52
Adult density	4	NDVI	RUG1	P_SOUTH[e]	0.52	0.08
Lamb density	2	NDVI			0.57	0.32
Lamb density	3	NDVI	P_ESC[f]		0.58	0.12
Lamb density	4	NDVI	P_SOUTH	P_WEST[g]	0.60	0.03
Total density	2	NDVI			0.42	0.22
Total density	3	NDVI	RUG1		0.51	0.42
Total density	4	NDVI	RUG1	PARA[h]	0.54	0.09

a) Number of parameters estimated including intercept
b) Weight of evidence in favor of each model using Akaike's information criterion for small sample sizes
c) NDVI was the normalized difference vegetation index which estimates relative greenness from reflectance values in satellite imagery (Markon *et al.* 1995, Shippert *et al.* 1995)
d) Terrain ruggedness estimated using a planar: surface area ratio with surface area estimated using a 60m DEM (Hobson 1972)
e) % south (120-210°) facing slopes
f) % escape terrain with escape terrain defined as >60% slope with a 150m buffer of >40% slope (McKinney *et al.* 2003)
g) % west (210-300°) facing slope in survey units
h) Perimeter: area ratio of escape terrain patches with escape terrain defined as >60% slope with a 150m buffer of >40% slope (McKinney *et al.* 2003)

Table 2.3. All habitat models using ≤ 2 variables predicting Dall's sheep density in Wrangell-St. Elias National Park and Preserve, Alaska, ranked by AICc (Δ_i). Models were evaluated using Akaike's Information Criteria adjusted for small sample size (AIC_C). The "best model" has a smaller AIC_C (Burnham and Anderson 2002). Mean densities (adult sheep/km^2) were estimated from 1967-2002 aerial survey unit data. *(Continued on following page)*

MODEL[a]		K[b]	r^2	AICc[c]	Δ_i[d]	w_i[e]
NDVI[f]	RUG1[g]	3	0.51	52.44	0.00	0.42
NDVI		2	0.42	53.76	1.32	0.22
NDVI	P_SOUTH[h]	3	0.44	55.65	3.21	0.09
NDVI	KM2_ESC[i]	3	0.42	56.16	3.73	0.07
NDVI	P_ESC[j]	3	0.42	56.17	3.73	0.07
NDVI	PARA[k]	3	0.42	56.39	3.96	0.06
NDVI	P_WEST[l]	3	0.42	56.45	4.02	0.06
RUG1	PARA	3	0.27	61.37	8.94	0.00
PARA		2	0.16	61.73	9.30	0.00
KM2_ESC		2	0.09	63.49	11.05	0.00
PARA	P_SOUTH	3	0.18	63.96	11.52	0.00
P_ESC	PARA	3	0.17	64.14	11.70	0.00
PARA	P_WEST	3	0.16	64.41	11.98	0.00
PARA	KM2_ESC	3	0.16	64.43	12.00	0.00
P_ESC	KM2_ESC	3	0.16	64.50	12.06	0.00
KM2_ESC	P_SOUTH	3	0.15	64.69	12.26	0.00
P_SOUTH		2	0.04	64.80	12.36	0.00
RUG1	KM2_ESC	3	0.15	64.83	12.40	0.00
RUG1		2	0.02	65.15	12.71	0.00
P_WEST		2	0.00	65.54	13.10	0.00
P_ESC		2	0.00	65.61	13.17	0.00
KM2_ESC	P_WEST	3	0.09	66.18	13.75	0.00
RUG1	P_SOUTH	3	0.05	67.08	14.64	0.00
P_ESC	P_SOUTH	3	0.04	67.43	14.99	0.00
P_SOUTH	P_WEST	3	0.04	67.48	15.05	0.00
RUG1	P_WEST	3	0.03	67.76	15.33	0.00
RUG1	P_ESC	3	0.02	67.77	15.33	0.00
P_ESC	P_WEST	3	0.00	68.24	15.80	0.00

a) Independent habitat variables in linear multiple regression model
b) number of parameters estimated including intercept
c) Akaike's information criterion for small sample sizes (Burnham and Anderson 2002)
d) Difference between the top model and subsequent models
e) Weight of evidence in favor of each model

Table 2.3. *Continued.* All habitat models using $\leq$ 2 variables predicting Dall's sheep density in Wrangell-St. Elias National Park and Preserve, Alaska, ranked by AICc (Δ_i). Models were evaluated using Akaike's Information Criteria adjusted for small sample size (AIC_C). The "best model" has a smaller AIC_C (Burnham and Anderson 2002). Mean densities (adult sheep/km^2) were estimated from 1967-2002 aerial survey unit data.

f) NDVI was the normalized difference vegetation index which estimates relative greenness from reflectance values in satellite imagery (Markon *et al.* 1995, Shippert *et al.* 1995)
g) Terrain ruggedness estimated using a planar: surface area ratio with surface area estimated using a 60m DEM (Hobson 1972)
h) % south (120-210°) facing slopes
i) Mean area (km^2) of escape terrain patches in a survey unit with escape terrain defined as >60% slope with a 150m buffer of >40% slope (McKinney *et al.* 2003)
j) % escape terrain with escape terrain defined as >60% slope with a 150m buffer of >40% slope (McKinney *et al.* 2003)
k) Perimeter: area ratio of escape terrain patches with escape terrain defined as >60% slope with a 150m buffer of >40% slope (McKinney *et al.* 2003)
l) % west (210-300°) facing slopes

Table 2.4. All models using ≤ 2 variables predicting mean reported harvest of Dall's sheep in Wrangell-St. Elias National Park and Preserve, Alaska, ranked by AICc (Δ_i). Models were evaluated using Akaike's Information Criteria adjusted for small sample size (AIC_C). The "best model" has a smaller AIC_C (Burnham and Anderson 2002). Mean harvest was estimated for survey units from 1983-2002 data. (*Continued next page*)

MODEL[a]		K[a]	R^2	AICc[c]	Δ_i[d]	w_i[e]
MN_DEN[f]		2	0.09	55.32	0.00	0.08
RUG1[g]		2	0.07	55.85	0.53	0.06
P_SOUTH[h]		2	0.06	55.91	0.58	0.06
P_WEST[i]		2	0.06	55.98	0.66	0.06
MN_DEN	P_SOUTH	3	0.18	56.41	1.09	0.05
NDVI[j]		2	0.04	56.42	1.10	0.05
PARA[k]		2	0.03	56.51	1.18	0.05
P_SOUTH	P_WEST	3	0.17	56.64	1.32	0.04
P_ESC[l]		2	0.02	56.83	1.51	0.04
KM2_ESC[m]		2	0.01	57.00	1.68	0.04
MN_DEN	P_WEST	3	0.15	57.10	1.78	0.03
MN_DEN	RUG1	3	0.13	57.46	2.14	0.03
RUG1	P_WEST	3	0.11	57.89	2.57	0.02
MN_DEN	P_ESC	3	0.11	57.94	2.61	0.02
PARA	P_SOUTH	3	0.11	57.95	2.63	0.02
NDVI	P_SOUTH	3	0.10	58.04	2.72	0.02
RUG1	P_SOUTH	3	0.10	58.04	2.72	0.02
MN_DEN	NDVI	3	0.10	58.12	2.80	0.02
MN_DEN	PARA	3	0.10	58.13	2.81	0.02
MN_DEN	KM2_ESC	3	0.10	58.16	2.83	0.02
NDVI	P_WEST	3	0.09	58.36	3.03	0.02
RUG1	KM2_ESC	3	0.09	58.36	3.04	0.02
RUG1	P_ESC	3	0.08	58.46	3.14	0.02
NDVI	RUG1	3	0.08	58.48	3.15	0.02
PARA	P_WEST	3	0.08	58.48	3.15	0.02
P_ESC	P_SOUTH	3	0.07	58.57	3.24	0.02
RUG1	PARA	3	0.07	58.65	3.32	0.02
KM2_ESC	P_SOUTH	3	0.07	58.74	3.41	0.02
KM2_ESC	P_WEST	3	0.06	58.82	3.49	0.01
P_ESC	P_WEST	3	0.06	58.83	3.51	0.01
PARA	KM2_ESC	3	0.05	59.12	3.80	0.01
NDVI	P_ESC	3	0.05	59.13	3.81	0.01
NDVI	PARA	3	0.04	59.15	3.83	0.01

Table 2.4. *Continued.* All models using ≤ 2 variables predicting mean reported harvest of Dall's sheep in Wrangell-St. Elias National Park and Preserve, Alaska, ranked by AICc (Δ_i). Models were evaluated using Akaike's Information Criteria adjusted for small sample size (AIC_C). The "best model" has a smaller AIC_C (Burnham and Anderson 2002). Mean harvest was estimated for survey units from 1983-2002 data.

MODEL[a]		K[a]	R^2	AICc[c]	Δ_i[d]	w_i[e]
NDVI	KM2_ESC	3	0.04	59.22	3.90	0.01
P_ESC	PARA	3	0.04	59.28	3.96	0.01
P_ESC	KM2_ESC	3	0.02	59.68	4.35	0.01

a) Independent habitat variables in linear multiple regression model
b) Number of parameters estimated including intercept
c) Akaike's information criterion for small sample sizes (Burnham and Anderson 2002)
d) Difference between the top model and subsequent models
e) Weight of evidence in favor of each model
f) Mean sheep density (km^2) based on fixed wing surveys conducted between 1967-2002
g) Terrain ruggedness estimated using a planar: surface area ratio with surface area estimated using a 60m DEM (Hobson 1972)
h) % south (120-210°) facing slopes
i) % west (210-300°) facing slope
j) NDVI was the normalized difference vegetation index which estimates relative greenness from reflectance values in satellite imagery (Markon *et al.* 1995, Shippert *et al.* 1995)
k) Perimeter: area ratio of escape terrain patches with escape terrain defined as >60% slope with a 150m buffer of >40% slope (McKinney *et al.* 2003)
l) % escape terrain with escape terrain defined as >60% slope with a 150m buffer of >40% slope (McKinney *et al.* 2003)
m) Mean area (km^2) of escape terrain patches in a survey unit with escape terrain defined as >60% slope with a 150m buffer of >40% slope (McKinney *et al.* 2003)

Table 2.5. All models using ≤ 2 variables predicting mean horn length residuals, from the regression of length on age, of Dall's sheep rams in Wrangell-St. Elias National Park and Preserve, Alaska, ranked by AICc (Δ_i). Models were evaluated using Akaike's Information Criteria adjusted for small sample size (AIC_C). "Best models" have a smaller AIC_C (Burnham and Anderson 2002). Mean horn length was estimated for survey units from 1983-2002 hunter-reported data. (*Continued next page*)

MODEL[a]		K[b]	r^2	AICc[c]	Δ_i[d]	w_i[e]
RUG1[f]		2	0.26	184.61	0.00	
MN_DEN[g]	RUG1	3	0.34	185.45	0.84	0.08
PARA[h]		2	0.21	185.66	1.05	0.07
KM2_ESC[i]		2	0.21	185.80	1.19	0.07
RUG1	PARA	3	0.31	186.20	1.59	0.05
MN_DEN	P_ESC[j]	3	0.30	186.52	1.91	0.05
RUG1	KM2_ESC	3	0.28	186.96	2.36	0.04
MN_DEN	KM2_ESC	3	0.28	187.03	2.42	0.04
MN_DEN		2	0.16	186.71	2.10	0.04
P_ESC	PARA	3	0.27	187.25	2.64	0.03
RUG1	P_SOUTH[k]	3	0.27	187.30	2.69	0.03
P_ESC		2	0.15	187.04	2.43	0.04
NDVI[l]	RUG1	3	0.26	187.44	2.83	0.03
RUG1	P_WEST[m]	3	0.26	187.44	2.83	0.03
MN_DEN	PARA	3	0.26	187.46	2.86	0.03
RUG1	P_ESC	3	0.26	187.52	2.91	0.03
PARA	KM2_ESC	3	0.23	188.10	3.49	0.02
PARA	P_SOUTH	3	0.22	188.33	3.73	0.02
P_ESC	KM2_ESC	3	0.22	188.48	3.88	0.02
PARA	P_WEST	3	0.21	188.49	3.89	0.02
NDVI	PARA	3	0.21	188.50	3.90	0.02
KM2_ESC	P_WEST	3	0.21	188.63	4.03	0.02
NDVI	KM2_ESC	3	0.21	188.64	4.03	0.02
KM2_ESC	P_SOUTH	3	0.21	188.71	4.10	0.02
NDVI		2	0.06	188.91	4.30	0.01
MN_DEN	P_WEST	3	0.18	189.28	4.68	0.01
MN_DEN	P_SOUTH	3	0.18	189.36	4.75	0.01
NDVI	P_ESC	3	0.17	189.42	4.82	0.01
MN_DEN	NDVI	3	0.17	189.43	4.82	0.01
P_WEST		2	0.02	189.53	4.92	0.01
P_ESC	P_WEST	3	0.15	189.87	5.26	0.01
P_ESC	P_SOUTH	3	0.15	189.94	5.33	0.01

Table 2.5. *Continued.* All models using ≤ 2 variables predicting mean reported horn length residual adjusted for age of Dall's sheep rams in Wrangell-St. Elias National Park and Preserve, Alaska, ranked by AICc (Δ_i). Models were evaluated using Akaike's Information Criteria adjusted for small sample size (AIC_C). "Best models" have a smaller AIC_C (Burnham and Anderson 2002). Mean horn length was estimated for survey units from 1983-2002 hunter-reported data.

MODEL[a]		K^b	r^2	AICc[c]	Δ_i^d	w_i^e
P_SOUTH		2	0.00	189.85	5.25	0.01
NDVI	P_WEST	3	0.07	191.58	6.97	0.00
NDVI	P_SOUTH	3	0.06	191.75	7.14	0.00
P_SOUTH	P_WEST	3	0.03	192.23	7.62	0.00

a) Independent habitat variables in linear multiple regression model
b) Number of parameters estimated including intercept
c) Akaike's information criterion for small sample sizes (Burnham and Anderson 2002)
d) Difference between the top model and subsequent models
e) Weight of evidence in favor of each model
f) Terrain ruggedness estimated using a planar: surface area ratio with surface area estimated using a 60m DEM (Hobson 1972)
g) Mean sheep density (km^2) based on fixed wing surveys conducted between 1967-2002
h) Perimeter: area ratio of escape terrain patches with escape terrain defined as >60% slope with a 150m buffer of >40% slope (McKinney *et al.* 2003)
i) Mean area (km^2) of escape terrain patches in a survey unit with escape terrain defined as >60% slope with a 150m buffer of >40% slope % south (120-210°) facing slopes (McKinney *et al.* 2003)
j) % escape terrain with escape terrain defined as >60% slope with a 150m buffer of >40% slope (McKinney *et al.* 2003)
k) % south (120-210°) facing slopes
l) NDVI was the normalized difference vegetation index which estimates relative greenness from reflectance values in satellite imagery (Markon *et al.* 1995, Shippert *et al.* 1995)
m) % west (210-300°) facing slope

Table 2.6. Predicted mean densities of Dall's sheep for aerial survey units with <3 years of surveys in Wrangell-St. Elias National Park and Preserve, Alaska, ranked from lowest to highest. We used the model: (mean adult density) = 0.62 (SE = 0.52) + (standardized NDVI[g])* 1.09 (SE = 0.19) + (standardized RUG1[h])* 0.39 (SE = 0.14).

SU[a]	Lower Confid.[b]	Predicted Density[c]	Actual Mean[d]	Upper Confid.[e]	Surveys[f]
2	0.27	0.41	0.14	0.55	1973,1983
4E	0.38	0.52		0.66	
4W	0.35	0.50	0.29	0.65	1968, 1983
5W	0.37	0.54	0.18	0.71	1983
18	0.28	0.42	0.16	0.56	1983
23E	0.31	0.45		0.59	
24	0.31	0.45	0.04	0.58	1973,1983
25	0.32	0.46	0.02	0.59	1990,1991
29	0.32	0.45		0.59	
30	0.27	0.41	0.19	0.55	1973,1998
31	0.33	0.48		0.63	
32	0.34	0.49	0.75	0.64	2001

a) Survey unit identification code
b) Lower 95% confidence limit
c) Predicted mean adult sheep density (sheep/km^2)
d) Actual mean for survey units using 1-2 surveys
e) Upper 95% confidence limit
f) Years surveys were flown in survey units with 1-2 surveys.
g) Normalized difference vegetation index
h) Surface: planar area ratio with surface area estimated using a 60m Digital Elevation Model

GENERAL CONCLUSIONS

Dall's sheep surveys provide information about the numbers and population trends of sheep within WRST. Such surveys are the basis for biologists to make management decisions and to fulfill the Park's ANLICA mandate (Alaska National Interest Lands Conservation Act 5 sec. 8-03, 805 and 815, 1980). To monitor sheep trends effectively it is important that future researchers use existing, established SUs such that comparisons among years can be made. As it is unlikely that funding will allow for all units to be surveyed annually surveys should concentrate on units with extensive survey histories (SUs 9, 11, 12, 14, 21, and 22) with additional surveys using random selection without replacement until all units are surveyed.

With areas of survey units now estimated (Table 4) biologists should use densities rather than indices such as lamb:ewe ratios to monitor population status in survey units. Lamb: ewe ratios in WRST were fairly consistent at ~28 lambs:100 ewes and there were no significant differences among survey units in lamb:ewe ratios or lamb densities.

Approximately half of the variance in density in WRST was explained by our habitat model. Dall's sheep density in Wrangell-St. Elias National Park and Preserve was primarily a function of relative forage quantity (a high relative median NDVI) and rugged terrain. Harvest was not predicted by habitat. Fifty percent of horn length was predicted by age and no one habitat model explained the remaining variation. To our knowledge, these models are the first large-scale quantitative assessments of habitat for Dall's sheep and the first large-scale habitat assessments for mountain sheep to include a forage-related variable.

The predictive power of the density model (Table 2.7) could be tested in WRST by conducting at least 3 or more consecutive aerial surveys in areas with <3 annual surveys. We would expect our model to be most relevant for neighboring Kluane National Park, Yukon Territory which has similar climatic and latitudinal influences to WRST. It may also be relevant for Denali National Park, Alaska which has high densities similar to WRST (Singer 1984). We expect it to be less relevant for the Brooks Range, Alaska where sheep are less dense (Singer 1984) and which lies at higher latitude and in an arctic climate. These models may be improved with the consideration of additional sources of variation such as the spatial heterogeneity of snow cover in winter, wind scouring in relation to snow, climate (maritime vs. interior), landcover, and predator risk if these types of data become available.

APPENDIX A.

Metadata for Wrangell-St. Elias National Park & Preserve, Alaska digitized aerial survey units for Dall's sheep (*Ovis dalli*) and mountain goats (*Oreamnos americana*).

What does this data set describe?

Title: Dall's Sheep & Mountain Goat Aerial Survey Units within Wrangell-St. Elias NP&P.

Abstract: The count areas were originally delineated by Alaska Department of Fish and Game wildlife biologists in 1967 on several USGS 1:250,000 topographical maps to survey (count and classify) Dall's sheep (Ovis dalli dalli) and mountain goat (Oreamnos americana) survey units. Count areas were designed to cover the mountainous habitat of these animals within WRST and to encompass units of reasonable size for fixed-wing aerial surveys (4-6 hours of effort) using prominent geographical features for boundaries. These units are currently flown in cooperative effort between Alaska Department of Fish and Game and Park biologist. The units were not intended to define discrete populations of sheep.

Supplemental_Information: none

How should this data set be cited?

Miranda L. N. Terwilliger, Alaska Cooperative Fish & Wildlife Research Unit, January 1, 2005, Dall's Sheep & Mountain Goat Aerial Survey Units within Wrangell-St. Elias NP&P.: National Park Service, GIS Alaska Support Office, Anchorage, Alaska, USA.

Online Links:

http://www.nps.gov/akso/gis/wrst/

This is part of the following larger work.

Online Links:

<http://www.nps.gov/akso/gis/>

What geographic area does the data set cover?

West_Bounding_Coordinate: -144.922367

East_Bounding_Coordinate: -140.998289

North_Bounding_Coordinate: 62.802271

South_Bounding_Coordinate: 60.615756

Does the data set describe conditions during a particular time period?

Beginning_Date: 1967

Ending_Date: unknown

Currentness_Reference: ground condition

What is the general form of this data set?

Geospatial_Data_Presentation_Form: vector digital data

How does the data set represent geographic features?

a) How are geographic features stored in the data set?

This is a Vector data set. It contains the following vector data types (SDTS terminology): G-polygon (34)

b) What coordinate system is used to represent geographic features?

Horizontal positions are specified in geographic coordinates, that is, latitude and longitude. Latitudes are given to the nearest 0.000000. Longitudes are given to the nearest 0.000000. Latitude and longitude values are specified in Decimal degrees.

The horizontal datum used is North American Datum of 1927.

The ellipsoid used is Clarke 1866.

The semi-major axis of the ellipsoid used is 6378206.400000.

The flattening of the ellipsoid used is 1/294.978698.

How does the data set describe geographic features?

sheepngoat

FID

Internal feature number. (Source: ESRI)

Sequential unique whole numbers that are automatically generated.

Shape

Feature geometry. (Source: ESRI)

Coordinates defining the features.

ID

Range of values	
Minimum:	1
Maximum:	34

NAME

Survey Unit Name (Source: Terwilliger, Miranda L. N. 2005. An analysis of habitat suitability for Dall's sheep in Wrangell-St. Elias National Park and Preserve. MS Thesis, Univ. Alaska, Fairbanks, Alaska, USA.)

Value	Definition
	* Areas labeled east & west are done to imply perceived biological

	continuity - when possible these areas should be surveyed together.

SU

Survey Unit Number (Source: ADF&G and WRST)

Value	Definition

PLANAR_KM2

Planar (Flat) Surface Area in square kilometers (Source: Jenness, J. 2004. Surface Tools (surf_tools.avx) extension for ArcView 3.x, v. 1.4a. Jenness Enterprises. Available at: <http://www.jennessent.com/arcview/surface_tools.htm>.)

Value	Definition
square kilometers	

SURF_KM2

Suface Area in square kilometers (Source: Jenness, J. 2004. Surface Tools (surf_tools.avx) extension for ArcView 3.x, v. 1.4a. Jenness Enterprises. Available at: <http://www.jennessent.com/arcview/surface_tools.htm>.)

Value	Definition
square kilometers	

RUG1

Measure of terrain ruggedness - surface area: planar area ratio (Source: Hobson, R. D. 1972. Surface roughness in topography: quantitative approach in RJ Chorley, editor, Spatial Analysis in Geomorphology. British Geomorphological Research Group, London, Methuen, United Kingdom. AND Jenness, J. 2004. Surface Tools (surf_tools.avx) extension for ArcView 3.x, v. 1.4a. Jenness Enterprises. Available at: <http://www.jennessent.com/arcview/surface_tools.htm>.)

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)

Miranda L. N. Terwilliger, Alaska Cooperative Fish & Wildlife Research Unit

Who also contributed to the data set?

Craig Gardner, Alaska Department of Fish & Game

Jeff Gross, Alaska Department of Fish & Game

Carl Mitchell, National Park Service

Mason Reid, National Park Service

Brad Scotton, Alaska Department of Fish & Game

Robert Tobey, Alaska Department of Fish & Game

To whom should users address questions about the data?

National Park Service, Alaska Support Office

c/o GIS Team

GIS Specialist

2525 Gambell Street

Anchorage, AK 99503

USA

Please contact us via email. (voice)

(907) 264-5428 (FAX)

AKSO_Internet_Contact@nps.gov

Hours_of_Service: 8:00am- 5:00pm AST

Why was the data set created?

To meet park management and research needs.

How was the data set created?

From what previous works were the data drawn?

Alaska Department of Fish & Game USGS 1:250,000 scale topographic maps

(source 1 of 1)

Alaska Department of Fish & Game, 1967, Dall's sheep and mountain goat count areas..

Online Links:

none

Type_of_Source_Media: paper map

Source_Scale_Denominator: 250,000

Source_Contribution: Source was used to digitize maps.

How were the data generated, processed, and modified?

Date: January 1, 2005 (process 1 of 1)

The original map was 4 1:250,000 USGS quads taped together with the count area polygons, count# and count name hand drawn on them. Polgons were digitally drawn in the Alaska Albers projection with the aid of DRGs and DEMs.

Person who carried out this activity:

National Park Servicve, Alaska Support Office

c/o GIS Team

GIS Specialist

2535 Gambell Street

Anchorage, Alaska 99503

USA

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(907) 264-5428 (FAX)

AKSO_Internet_Contact@nps.gov

Hours_of_Service: 8:00am- 5:00pm AST

What similar or related data should the user be aware of?

How reliable are the data; what problems remain in the data set?

How well have the observations been checked?

All attributes were verified by visually comparing the attributes of the digital coverage against the original source material, but no formal tests were performed.

How accurate are the geographic locations?

Horizontal positional accuracy for the digital data is tested by visual comparison of the source with hard copy plots at 1:250,000.

How accurate are the heights or depths? N/A

Where are the gaps in the data? What is missing?

Dataset complete.

How consistent are the relationships among the observations, including topology?

Polygon topology present.

How can someone get a copy of the data set?

Are there legal restrictions on access or use of the data?

Access_Constraints: none

Use_Constraints: none

Who distributes the data set? (Distributor 1 of 1)

National Park Service, Alaska Support Office

c/o GIS Team

GIS Specialist

2525 Gambell Street

Anchorage, Alaska 99503

USA

Please contact us via email. (voice)

(907) 264-5428 (FAX)

AKSO_Internet_Contact@nps.gov

Hours_of_Service: 8:00am-5:00pm AST

What's the catalog number I need to order this data set?

Downloadable Data

What legal disclaimers am I supposed to read?

The National Park Service shall not be held liable for improper or incorrect use of the data described and/or contained herein. These data and related graphics (i.e. "GIF or JPG" format files) are not legal documents and are not intended to be used as such. The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived. It is the responsibility of the data user to use the data appropriately and consistent within the limitations of geospatial data in general and these data in particular. The related graphics are intended to aid the data user in acquiring relevant data; it is not appropriate to use the related graphics as data. The National Park Service gives no warranty, expressed or implied, as to the accuracy, reliability, or completeness of these data. It is strongly recommended that these data are directly acquired from an NPS server and not indirectly through other sources which may have changed the data in some way. Although these data have been processed successfully on computer systems at the National Park Service, no warranty expressed or implied is made regarding the utility of the data on other systems for general or scientific purposes, nor shall the act of distribution constitute any such warranty. This disclaimer applies both to individual use of the data and aggregate use with other data.

How can I download or order the data?

Availability in digital form:

Data format: Size: 0.165

Cost to order the data:

Is there some other way to get the data?

This data is available online at the AGDC clearinghouse at <http://agdc.usgs.gov> or at the National Park Service website at: <http://www.nps.gov/akso/gis>

Who wrote the metadata?

Last modified: 21-Jan-2005

Metadata author: Miranda L. N. Terwilliger

National Park Service, Alaska Support Office

c/o GIS Team

GIS Specialist

2525 Gambell Street

Anchorage, Alaska 99503

USA

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(907) 264-5428 (FAX)

AKSO_Internet_Contact@nps.gov

Hours_of_Service: 8:00am-5:00pm AST

Metadata standard:

FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

Metadata extensions used:

<http://www.esri.com/metadata/esriprof80.html>

APPENDIX B.

A written description of Dall's sheep (*Ovis dalli*) and mountain goat (*Oreamnos americana*) aerial survey units in Wrangell-St. Elias National Park & Preserve, Alaska, USA.

SU01 – Mentasta Mountains: Bordered by the Nabesna River to the east (including Boyden Hills), the Nabesna Road and Jack Creek to the south, Suslota Pass and Creek to the west, and Buck Creek (as if it kept running straight to the Nabesna River) to the north (Fig. C.1).

SU02 - Mount Sanford: Border by the Copper Glacier to the east, Sanford River and Glacier to the south, the flats to the west and north (Fig. C.2).

SU03 – Jacksina: Bordered by the Nabesna Glacier and River to the east, the Nabesna Glacier to the south, the Copper Glacier and River to the west, and the Nabesna Road and Jack Creek to the north (Fig. C.3).

SU04W - Nikonda Creek:* Bordered by the Cross Creek drainage to the east, the Nabesna Glacier to the south and west, and Cooper Pass and Creek to the north (Fig. C.4). Note: This was SU04 for ADF&G until 1981 when David Kelleyhouse combined it with what is now SU04E.

SU04E – Cross Creek:* Bordered by the Chisana Glacier and River to the east, the Nabesna Glacier to the south and west, and Cooper Pass and Creek to the north (Fig. C.5). Note: This area was considered part of SU06 prior to 1981 however, it was never surveyed before 2001.

SU05W – Stone Creek:* Bordered by Star Creek and Stuver Creek drainages to the east, Copper Creek and Pass to the south, the Nabesna River to the west, and the flats to the north (Fig. C.6).

SU05E - East Mount Allen:* Bordered by the Chisana River to the east, the flats to the north, the Star Creek and Stuver Creek drainages to the west, and Copper Pass and Creek to the north (Fig. C.7). Note: This area was numbered as SU06 prior to 2003.

SU07W – Chisana:* Bordered by Carl and Snag Creeks to the east, Beaver Creek to the south, the Chisana River to the west, and the flats to the north (Fig. C.8).

SU07E - Klein Creek:* Bordered by Canada to the east, Beaver Creek and Horsefeld to the south, Carl and Snag Creeks to the west, and the flats to the north (Fig. C.9). Note: This area was numbered as SU08 prior to 2003.

SU09 - Ptarmigan Lake: Bordered by Canada to the east, the White River flats to the south, Solo Flats to the west, and Horsefeld and Beaver Creek to the north (Fig. C.10).

SU10 - Mount Drum: Bordered by the Nabesna Glacier to the East, the Dadina Glacier and River to the south, the flats to the west, and the Sandford Glacier to the north (Fig. C.11).

SU11 – Chetaslina: Bordered by Long Glacier to the east, the flats to the south, Dadina Glacier to the west, and the Nabesna Glacier to the north (Fig. C.12).

SU12 - Kluvesna Glacier: Bordered by the left branch of the Kuskulana glacier to the east, the Strelna Creek road to the south, Long Glacier to the west, and the Nabesna Glacier to the north (Fig. C.13).

SU13 – Kuskulana Pass: Bordered by the Lakina Glacier to the east, the Gilahina River to the south, the left fork of the Kuskulana Glacier to the west, and the Nabesna Glacier to the north (Fig. C.14).

SU14 - Crystalline Hills: Nothing but the entirety of the Crystalline Hills bordered by the McCarthy Road to the south and the Gilahina River to the north (Fig. C.15).

SU15 - Fireweed Mountain: Bordered by the Root Glacier to the east, the Mill Creek and flats to the south, the Lakina Glacier to the west, and the Nabesna Glacier to the north (including Mountaineers Pass) (Fig. C.16).

SU16 – Bonanza Ridge: Bordered by the Nizina River and Glacier to the east, May Creek to the south, the Root Glacier to the west, and the Rohn Glacier to the north (Fig. C.17).

SU17 – Chitistone: Bordered by the Chitistone River and the Goat trail to the east, the Chitistone river to the south, the Nizina Glacier to the west, and Skolai Creek to the north (Fig. C.18).

SU18 - Frederika Mountain: Bordered by Skolai Pass, the Russell Glacier, and Solo Flats to the east, Skolai Creek to the north, the Nabesna Glacier to the west, and the Chisana Glacier and Solo Flats to the north (Fig. C.19).

SU19 - Mount Sulzer: Bordered by Canada to the east, the Klutan Glacier and Mount Churchill to the south, the Russell Glacier to the west, and the White River flats to the north (Fig. C.20).

SU20 – Chititu: Bordered by the Canyon Creek Glacier to the east, Young Creek to the south, the Nizina River to the west, the Chitistone River, Glacier Creek, and the Twaharpies Glacier to the north (Fig. C.21).

SU21 - MacColl Ridge: Nothing but the entirely of MacColl Ridge, bordered by Canyon Creek to the east, the Chitina River to the south, the flats to the west, and Young Creek and Big Bend Lakes to the north (Fig. C. 22).

SU22 –Hawkins Glacier: Bordered by Barnard Glacier to the east, the Chitina River to the south, Canyon Creek Glacier and the Twaharpies Range to the west, and Mount Churchill to the north (Fig. C.23).

SU23W - Chitina, Preserve:* Bordered by the WRST Park/ Canada boundary to the east, the Chitnia Glacier to the south, Barnard Glacier to the west, and Klutlan Glacier to the north (Fig. C.24).

SU23E - Chitina, Park:* Bordered by Anderson Glacier to the east, the Chitnia Glacier to the south, the WRST Preserve boundary to the west, and Klutlan Glacier to the north (Fig. C.25).

SU23 –Chitina, all: Bordered by the WRST Park/ Canada boundary to the east, the Chitina Glacier to the south, Barnard Glacier to the west, and Klutlan Glacier to the north.

SU24 – University Range: Bordered by the Twaharpies and the Russell Glacier to the east, the Twaharpies Glacier and Glacier creek to the south, the Chitistone River and the Goat Trail to the west, and Skolai Pass to the north (Fig. C.26).

SU25 - Spirit Mountain: Bordered by Tebay and Little Bremner Rivers to the east, the Bremner River to the south, the Copper River to the west, and the Chitina River to the north (Fig. C.27).

SU26 - Hanagita Peak: Bordered by Ptarmigan and Monahan Creeks to the east, the North Fork of the Bremner River to the south, Tebay and Little Bremner Rivers to the west, and the Hanagita River to the north (Fig. C.28).

SU27 - Nelson Mountain: Bordered by Chakina River to the east, the Hanagita River to the south, Tebay River to the west, and the Chitina River to the north (Fig. C.29).

SU28 – Goodlata Peak: Bordered by the Tana River to the east, the North Fork Lobe of the Bremner Glacier to the south, the Ptarmigan and Monahan Creeks to the west, and the flats to the north (Fig. C.30).

SU29 - Granite Creek: Bordered by the East Fork of the Kiagna River to the east, the Jefferies Glacier to the south, the Tana River and Glacier to the west, and the flats to the north (Fig. C.31).

SU30 - Goat Creek: Bordered by Bud Peak and glaciers to the east, the Jefferies Glacier to the south, the East Fork of the Kiagna River to the west, and the Chitina River to the north (Fig. C.32).

SU31 - Baldwin Glacier: Bordered by Canada to the east, the Jefferies Glacier to the south, Bud Peak and glaciers to the west, and the Logan Glacier to the north (Fig. C.33).

SU32 – Mount George: Bordered by Canada to the east, the Logan Glacier to the south, and the Chitina Glacier to the west, and the Anderson Glacier to the north (Fig. C.34).

* Areas labeled east & west are done so to imply perceived biological continuity – when possible these areas should be surveyed together.

APPENDIX C.

Graphical analyses of adult Dall's sheep densities (sheep/km^2) in Wrangell-St. Elias National Park and Preserve, Alaska. Graphs are presented for survey units with $\geq$3 fixed-wing aerial census surveys between 1949-2002. Densities were estimated using classified sheep information and surface area estimated for a 60m digital elevation model. Trends are depicted with trend lines, equations, and r^2 in survey units where they were detected. A lack of trend lines indicate that no trend was detected with existing data.

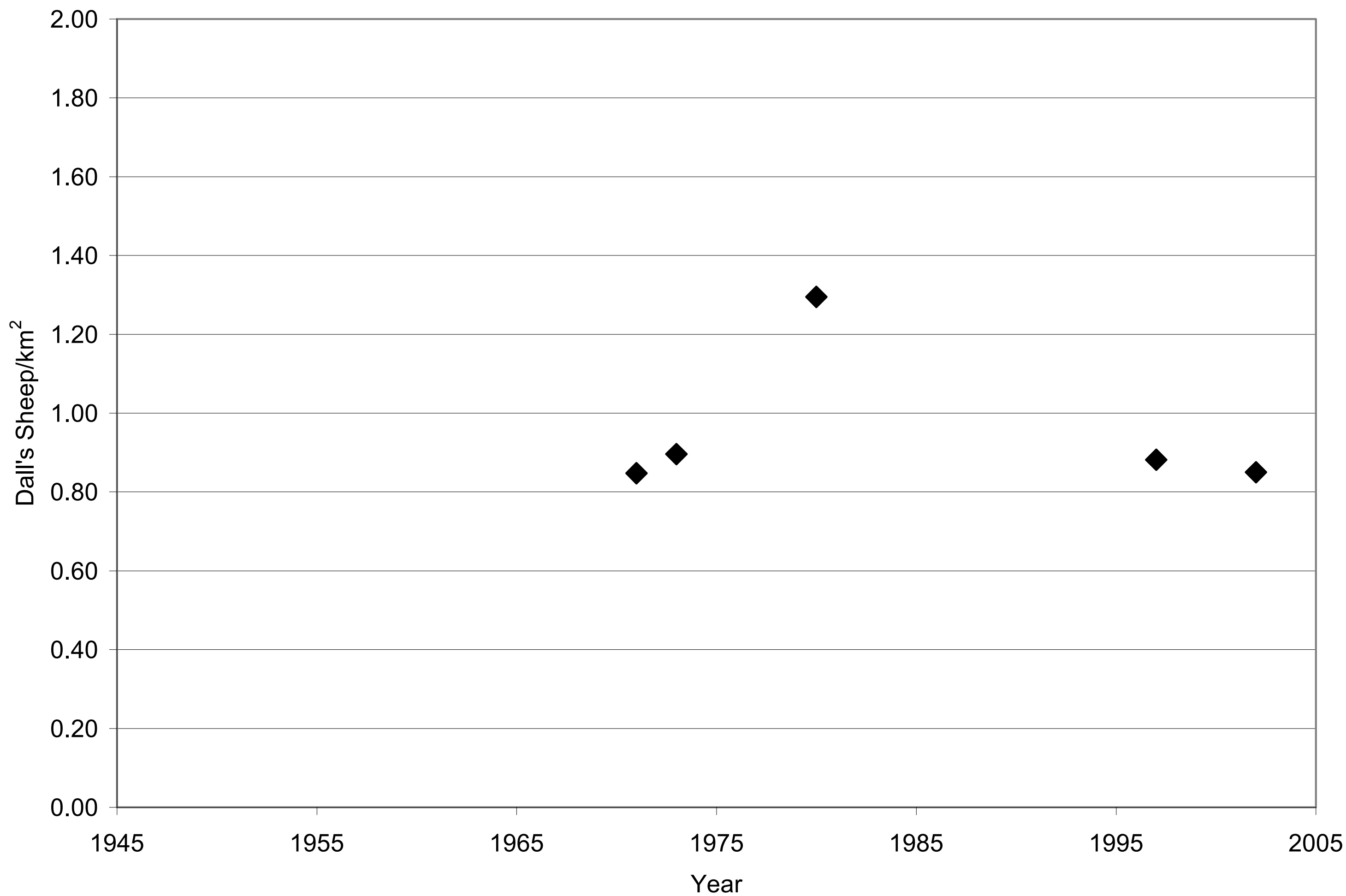

Figure C.1. Dall's sheep densities in survey unit 1, Mentasta Mountains, Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Densities were estimated using surface area estimated from a 60m digital elevation model.

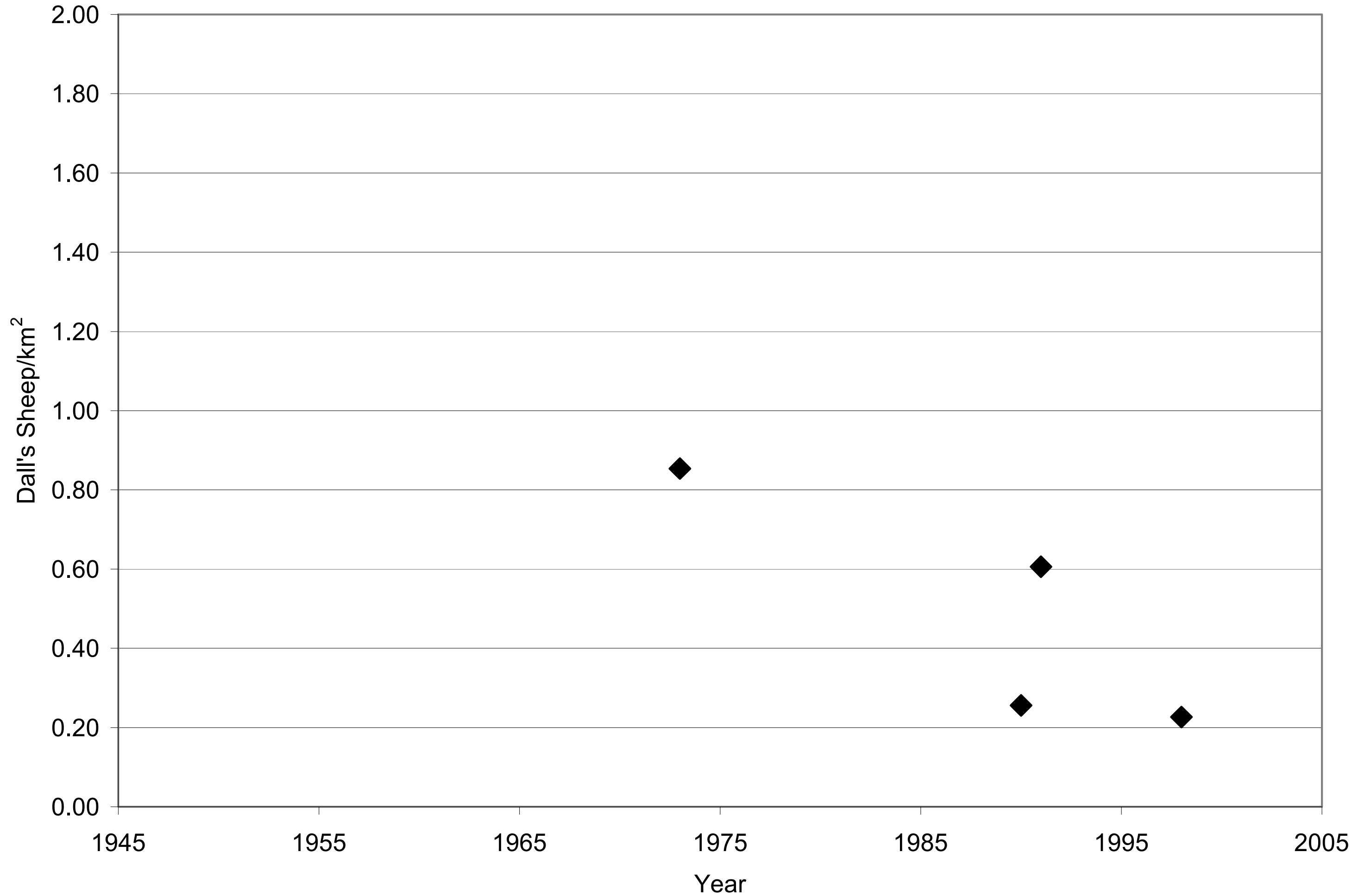

Figure C.2. Dall's sheep densities in survey unit 3, Jacksina, Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Densities were estimated using surface area estimated from a 60m digital elevation model

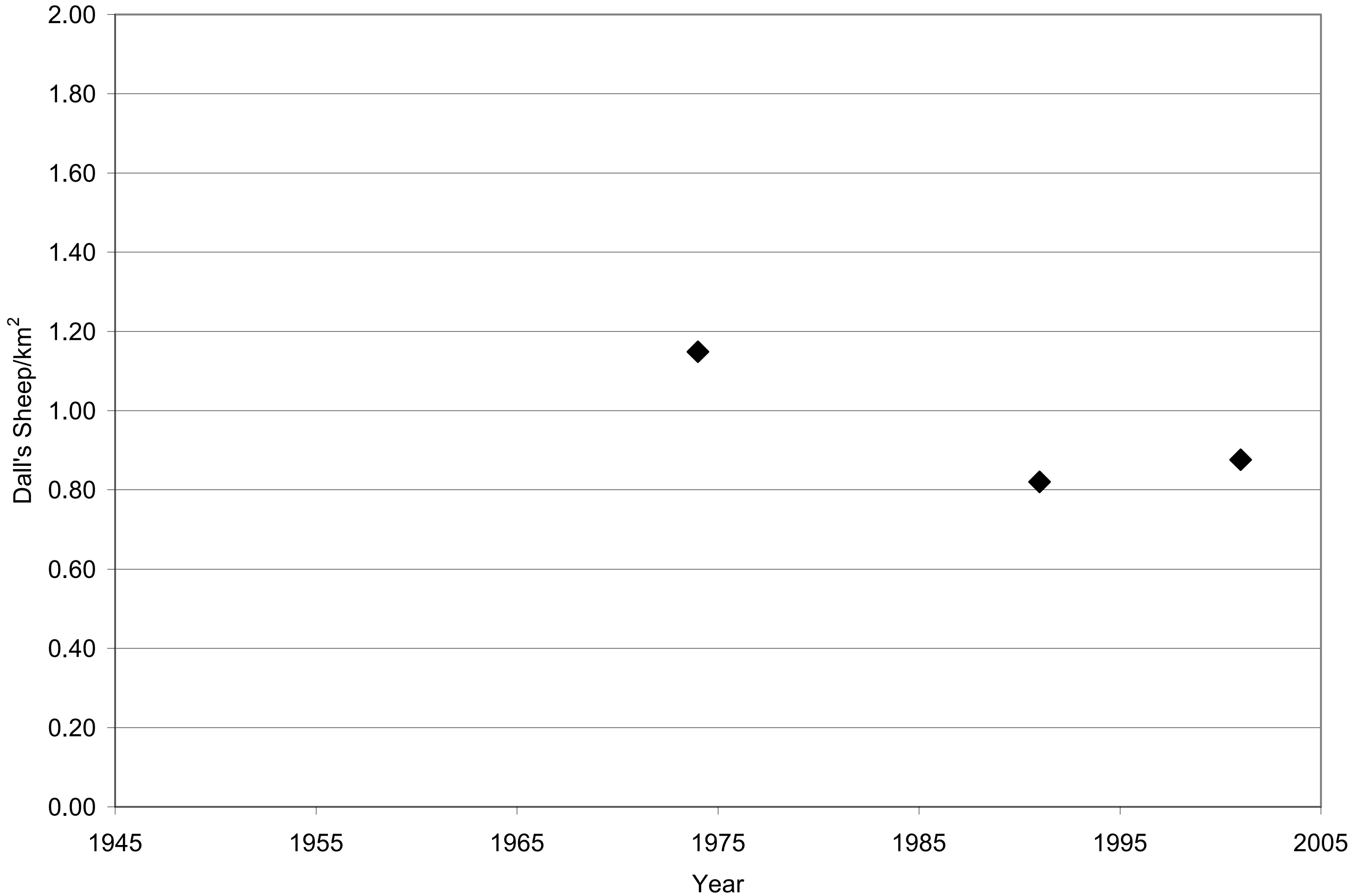

Figure C.3. Dall’s sheep densities in survey unit 5E, East Mount Allen, Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Densities were estimated using surface area estimated from a 60m digital elevation model

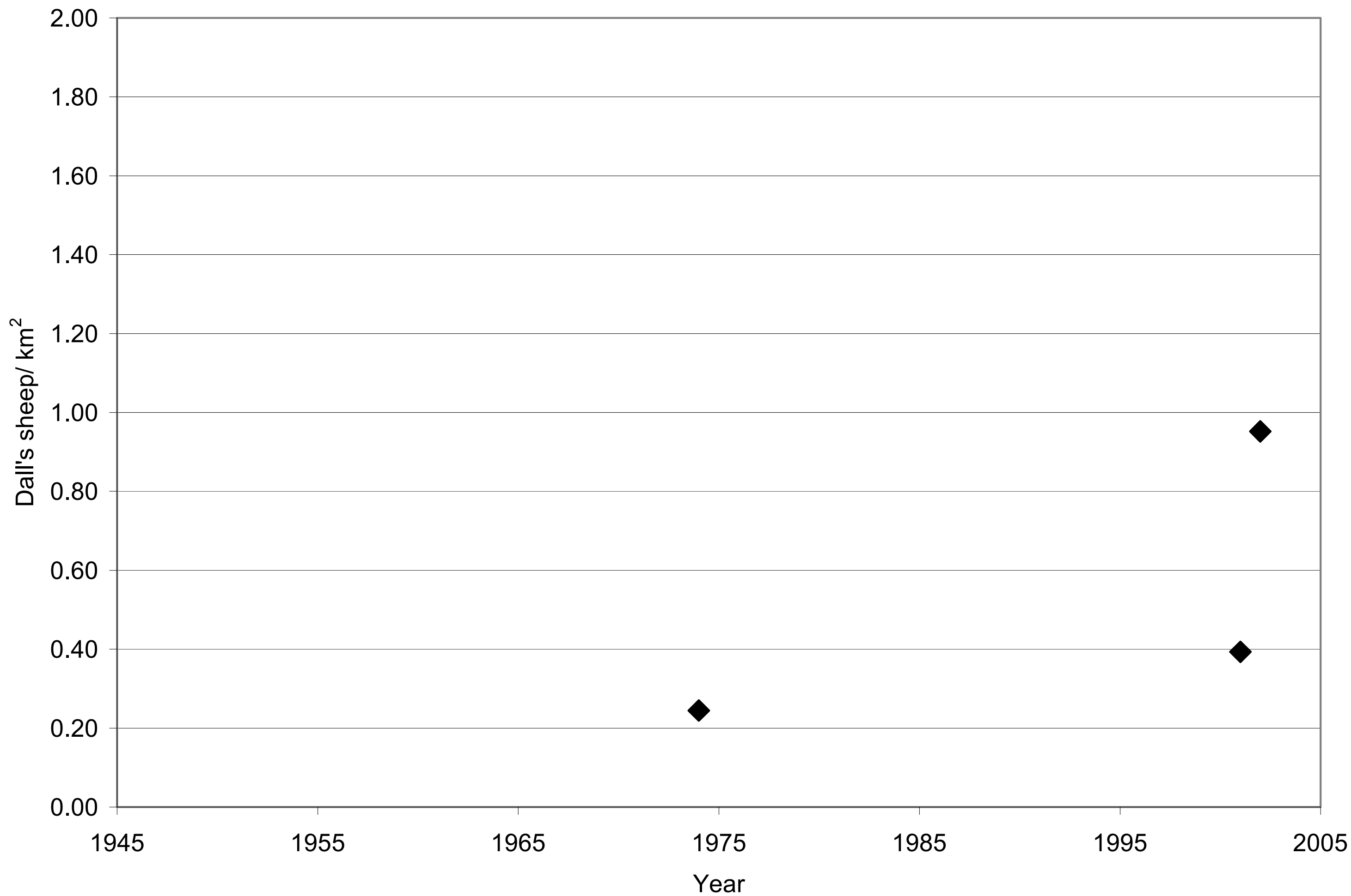

Figure C.4. Dall's sheep densities in survey unit 7E, Klein Creek, Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Densities were estimated using surface area estimated from a 60m digital elevation model.

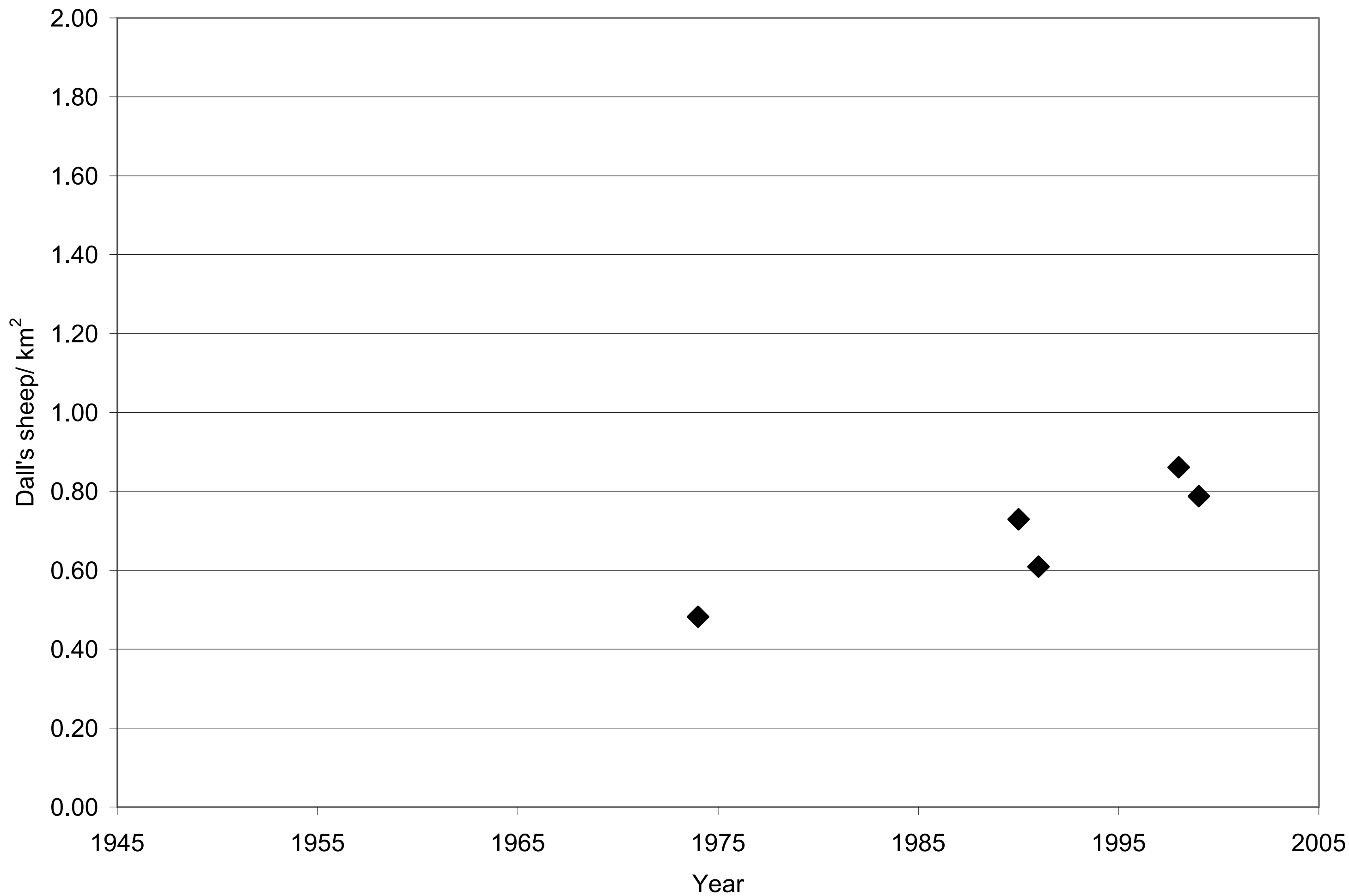

Figure C.5. Dall’s sheep densities in survey unit 7W, Chisana, Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Densities were estimated using surface area estimated from a 60m digital elevation model.

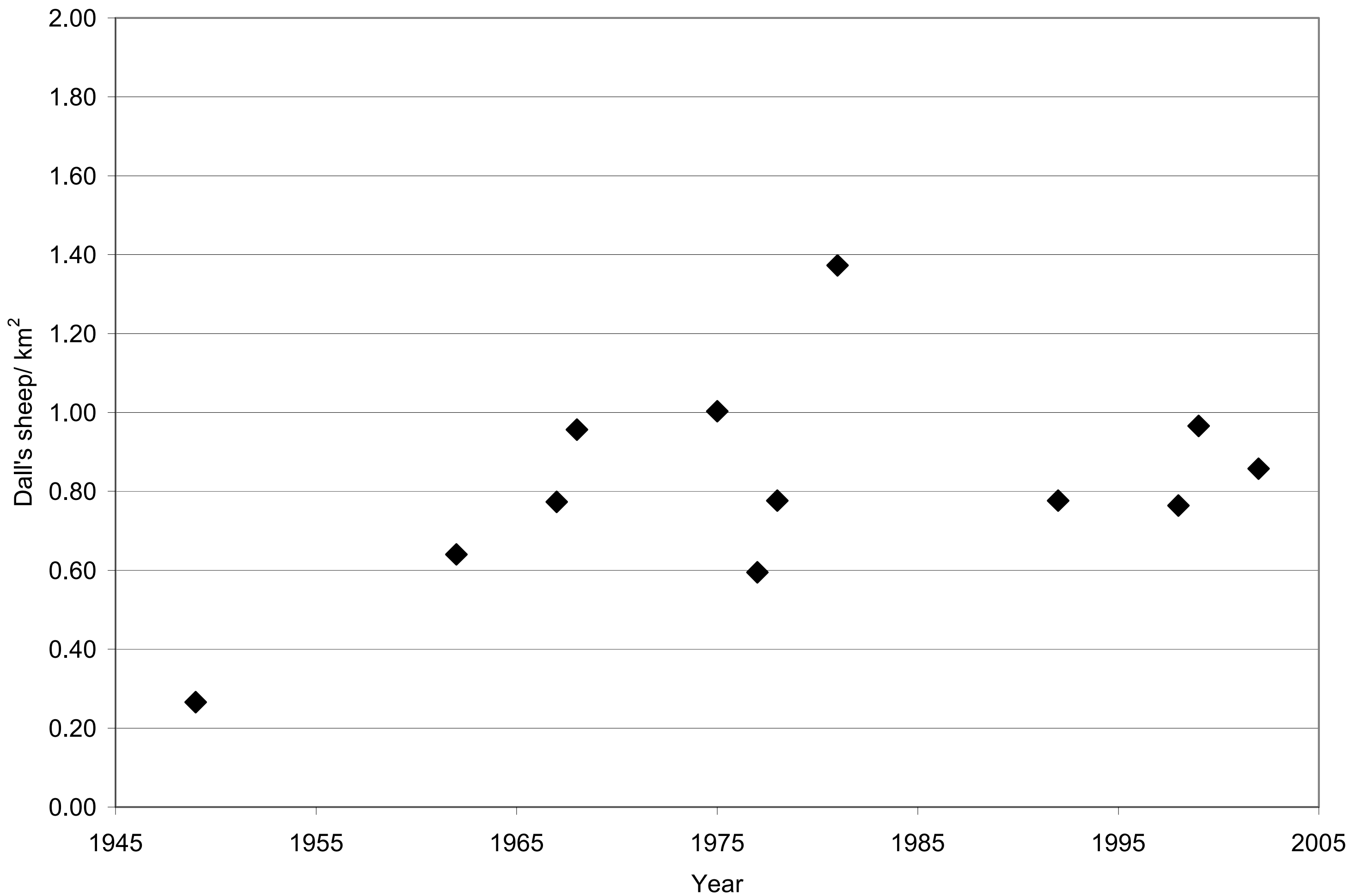

Figure C.6. Dall's sheep densities in survey unit 9, Ptarmigan Lake, Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Densities were estimated using surface area estimated from a 60m digital elevation model.

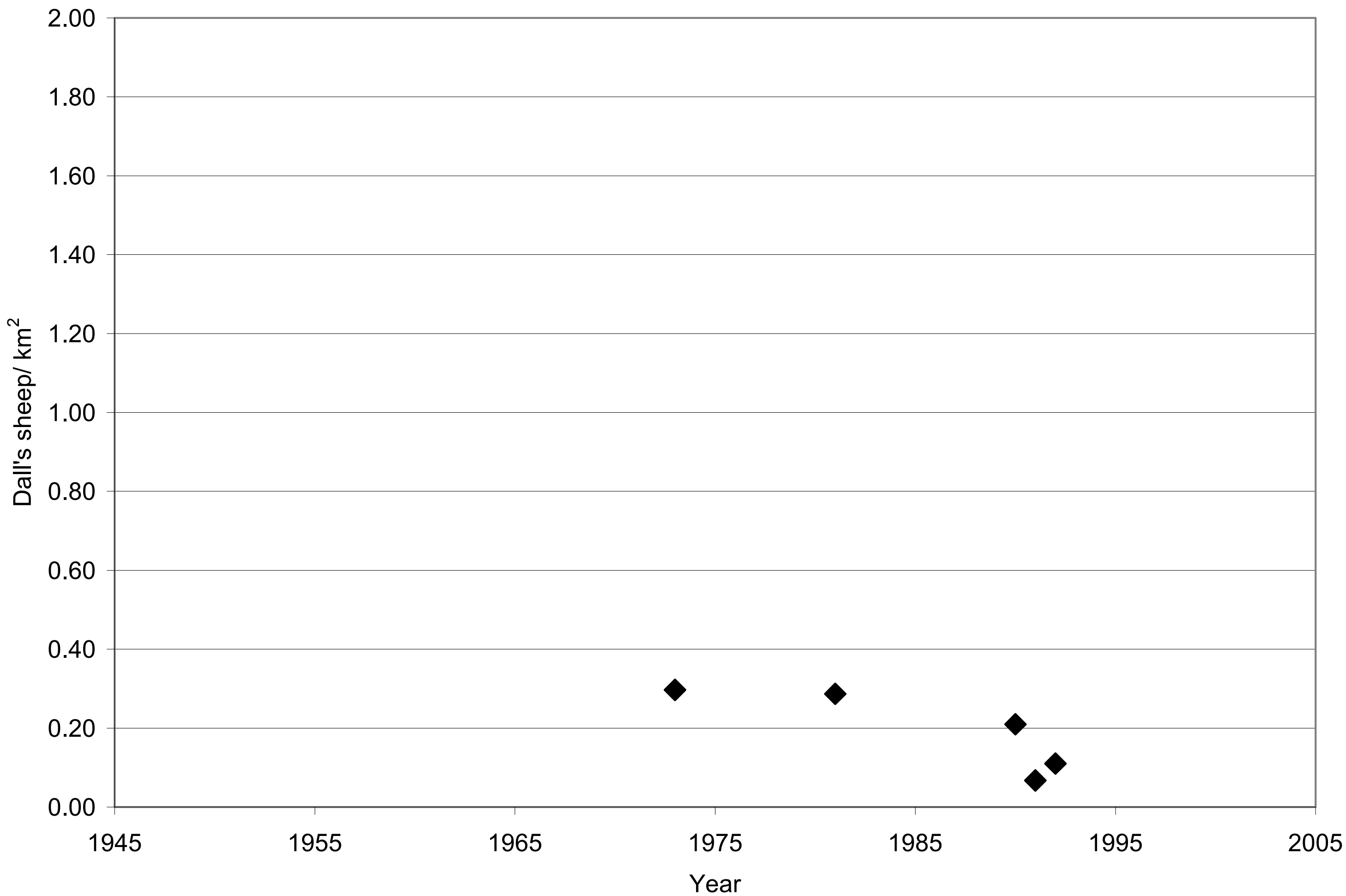

Figure C.7. Dall's sheep densities in survey unit 10, Mount Drum, Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Densities were estimated using surface area estimated from a 60m digital elevation model.

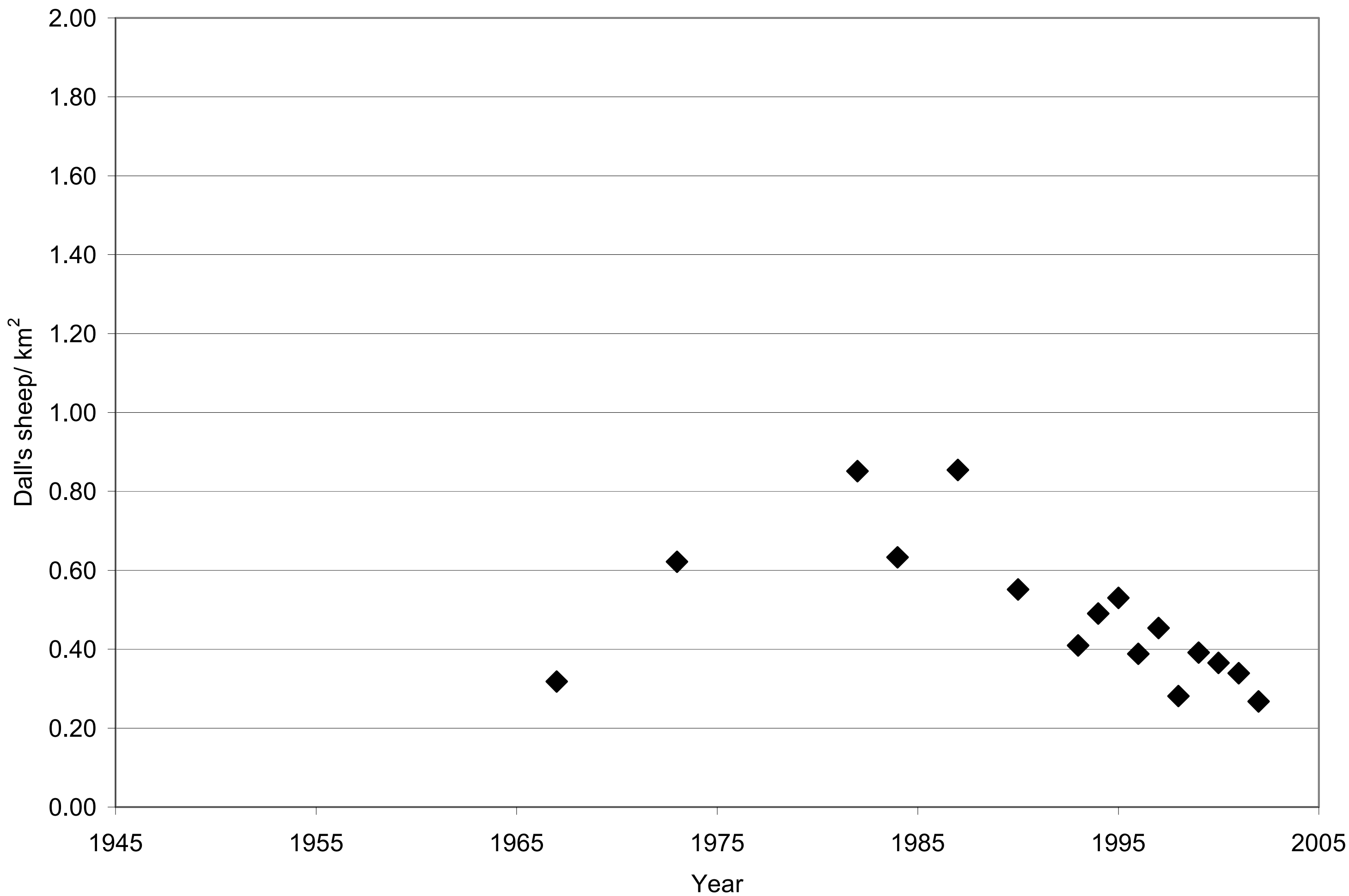

Figure C.8. Dall's sheep densities in survey unit 11, Chetaslina, Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Densities were estimated using surface area estimated from a 60m digital elevation model.

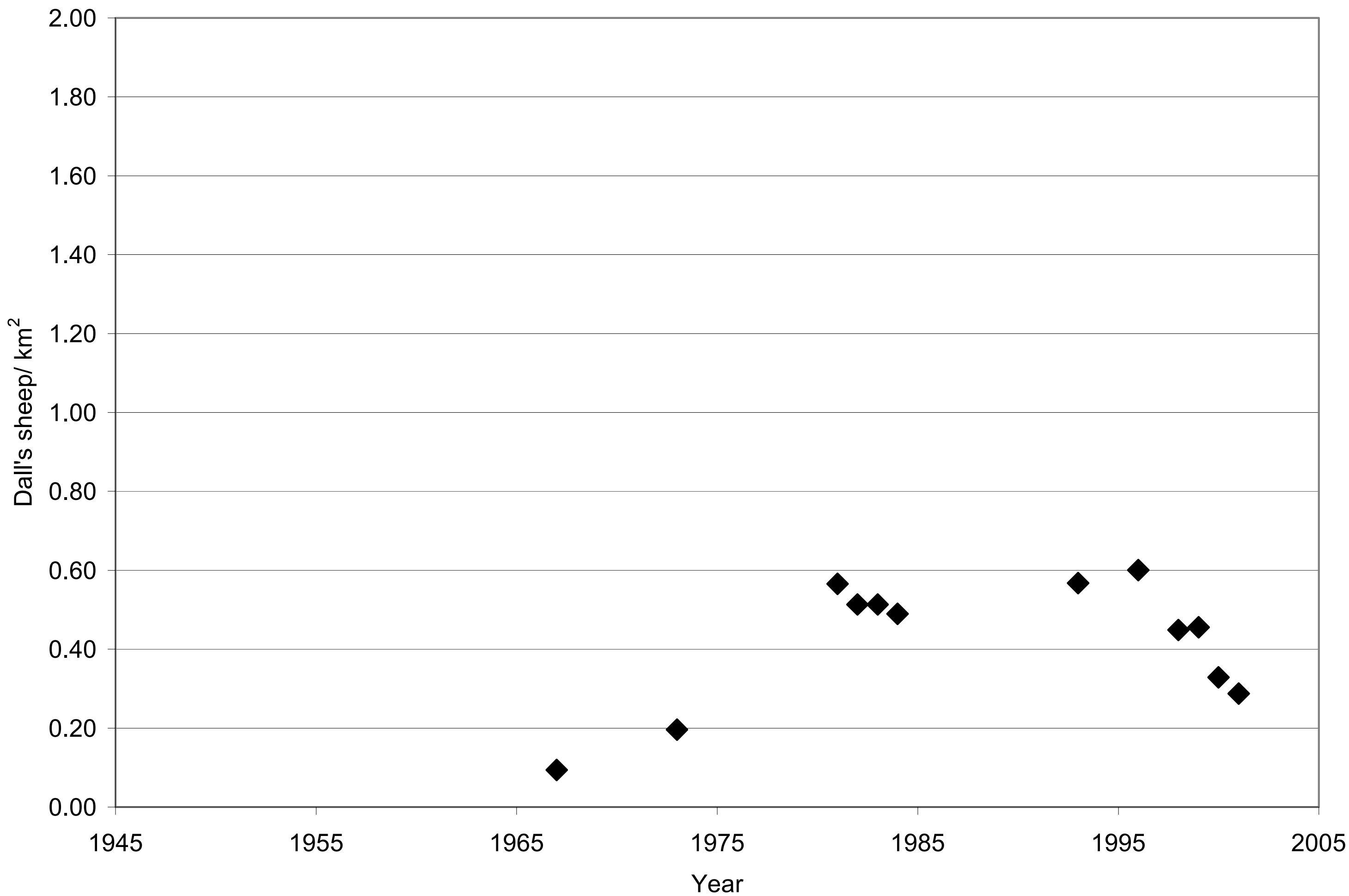

Figure C.9. Dall's sheep densities in survey unit 12, Kluvesna Glacier, Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Densities were estimated using surface area estimated from a 60m digital elevation model.

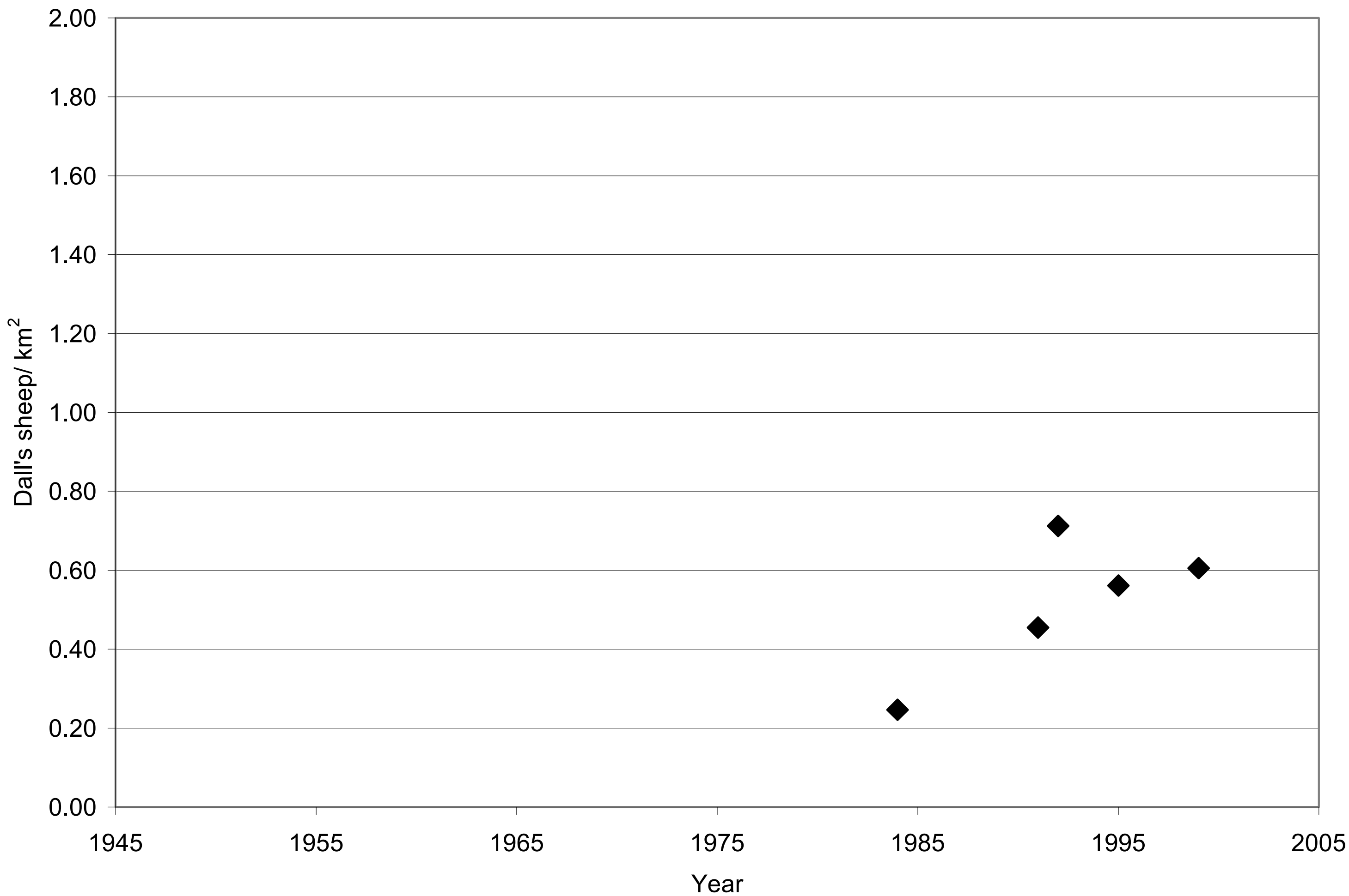

Figure C.10. Dall's sheep densities in survey unit 13, Kuskulana Pass, Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Densities were estimated using surface area estimated from a 60m digital elevation model.

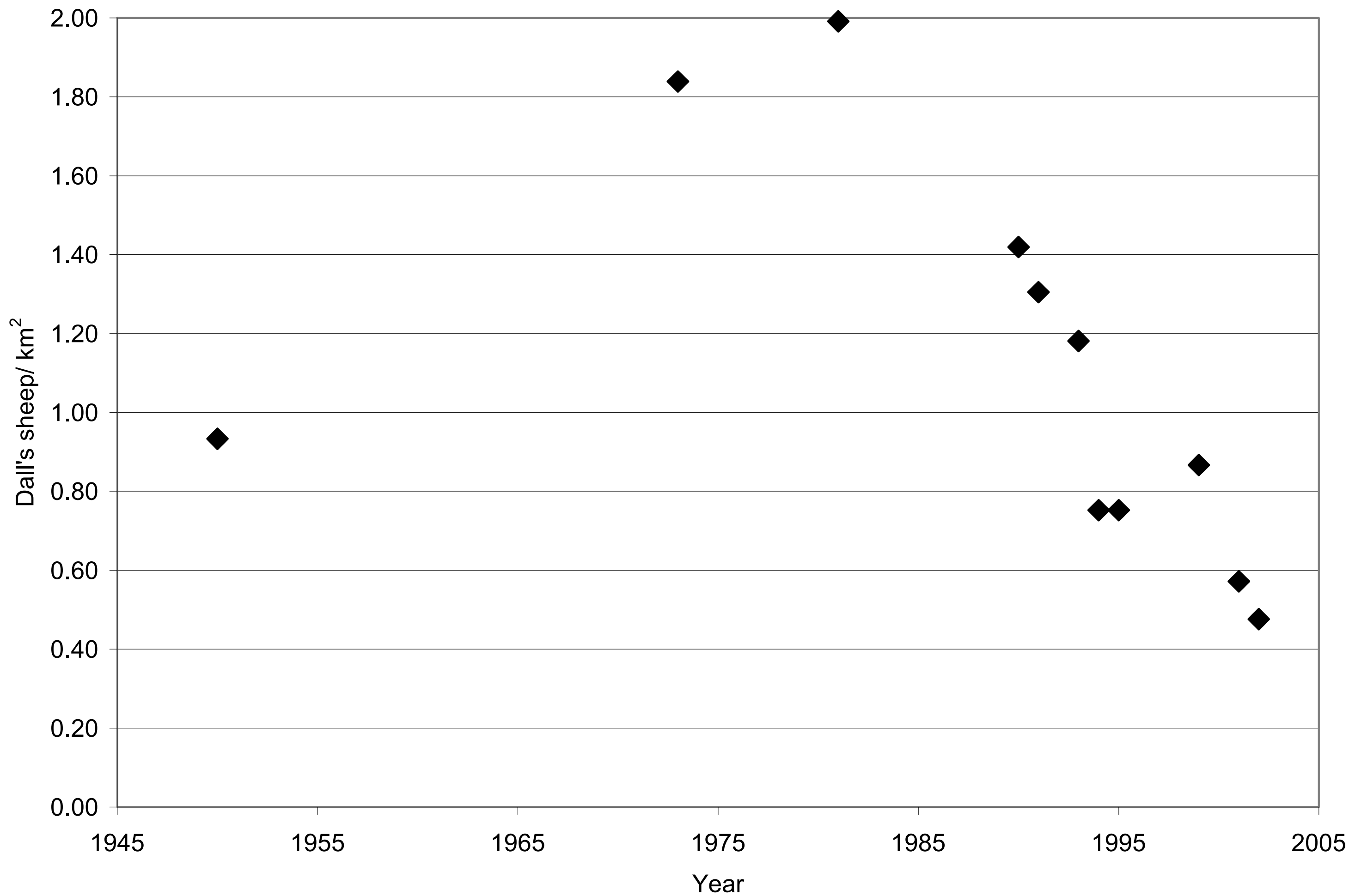

Figure C.11. Dall's sheep densities in survey unit 14 , Crystalline Hills, Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Densities were estimated using surface area estimated from a 60m digital elevation model.

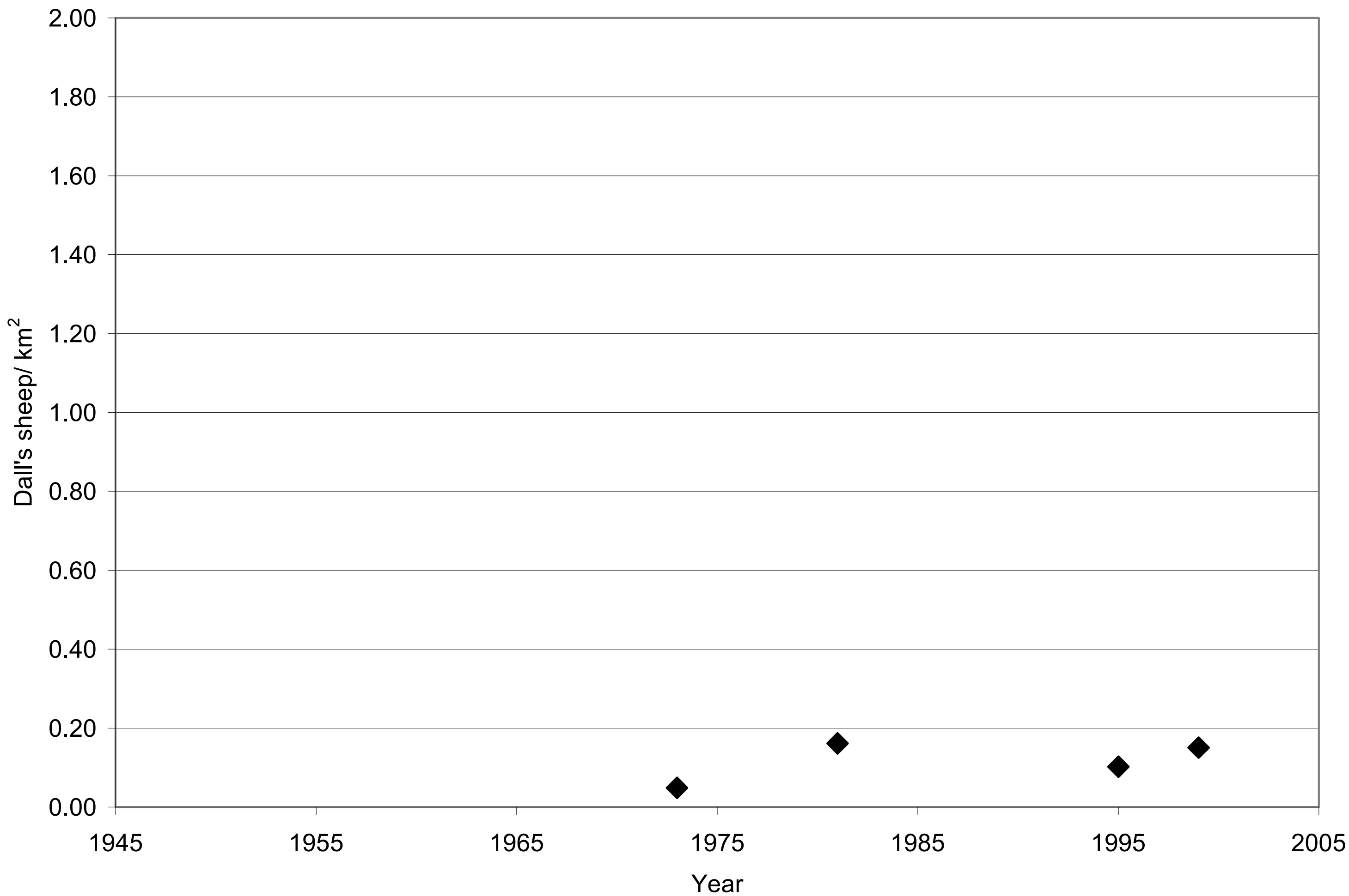

Figure C.12. Dall's sheep densities in for survey unit 15, Fireweed Mountain, Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Densities were estimated using surface area estimated from a 60m digital elevation model.

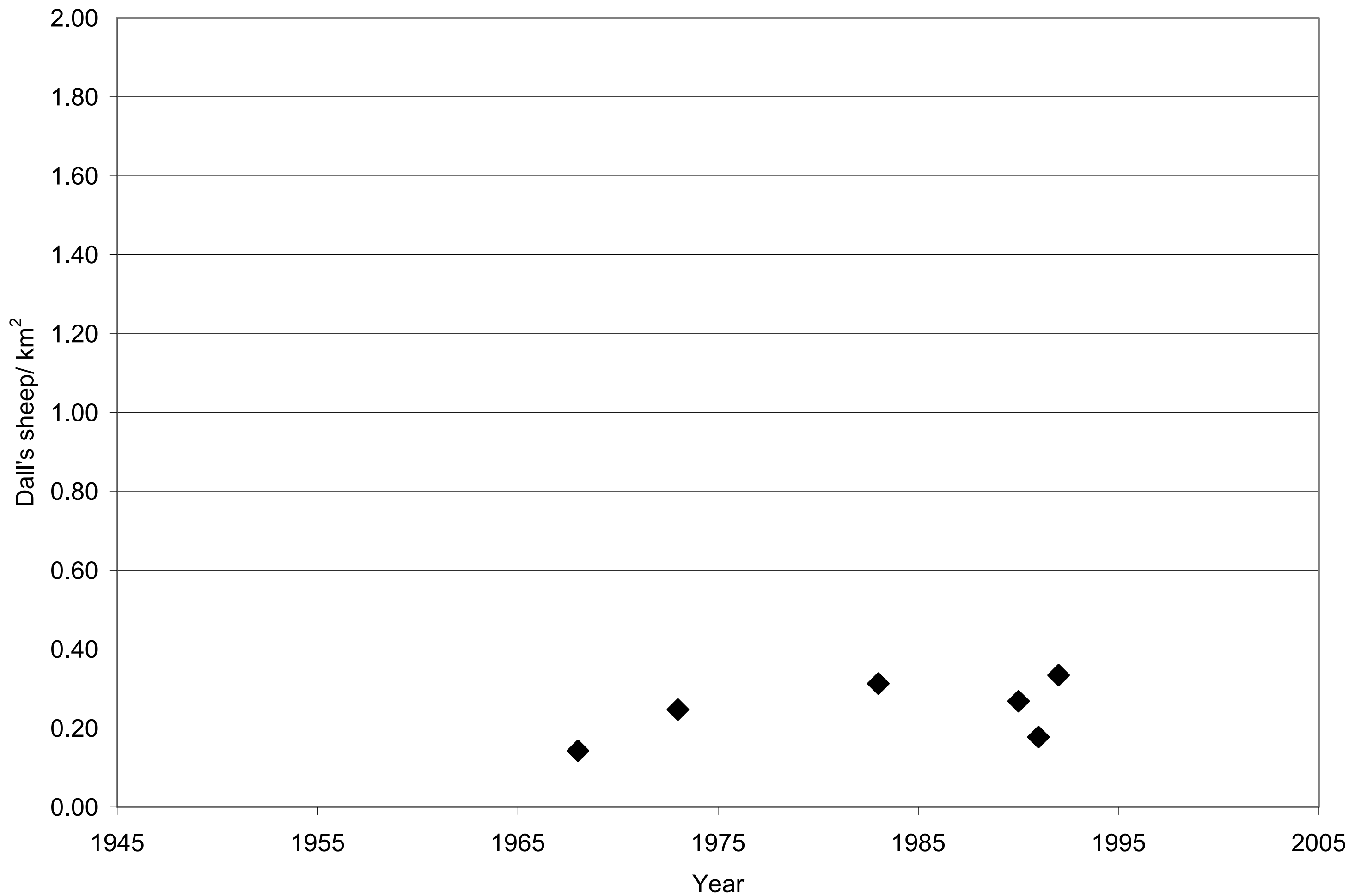

Figure C.13. Dall's sheep densities in survey unit 16, Bonanza Ridge, Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Densities were estimated using surface area estimated from a 60m digital elevation model.

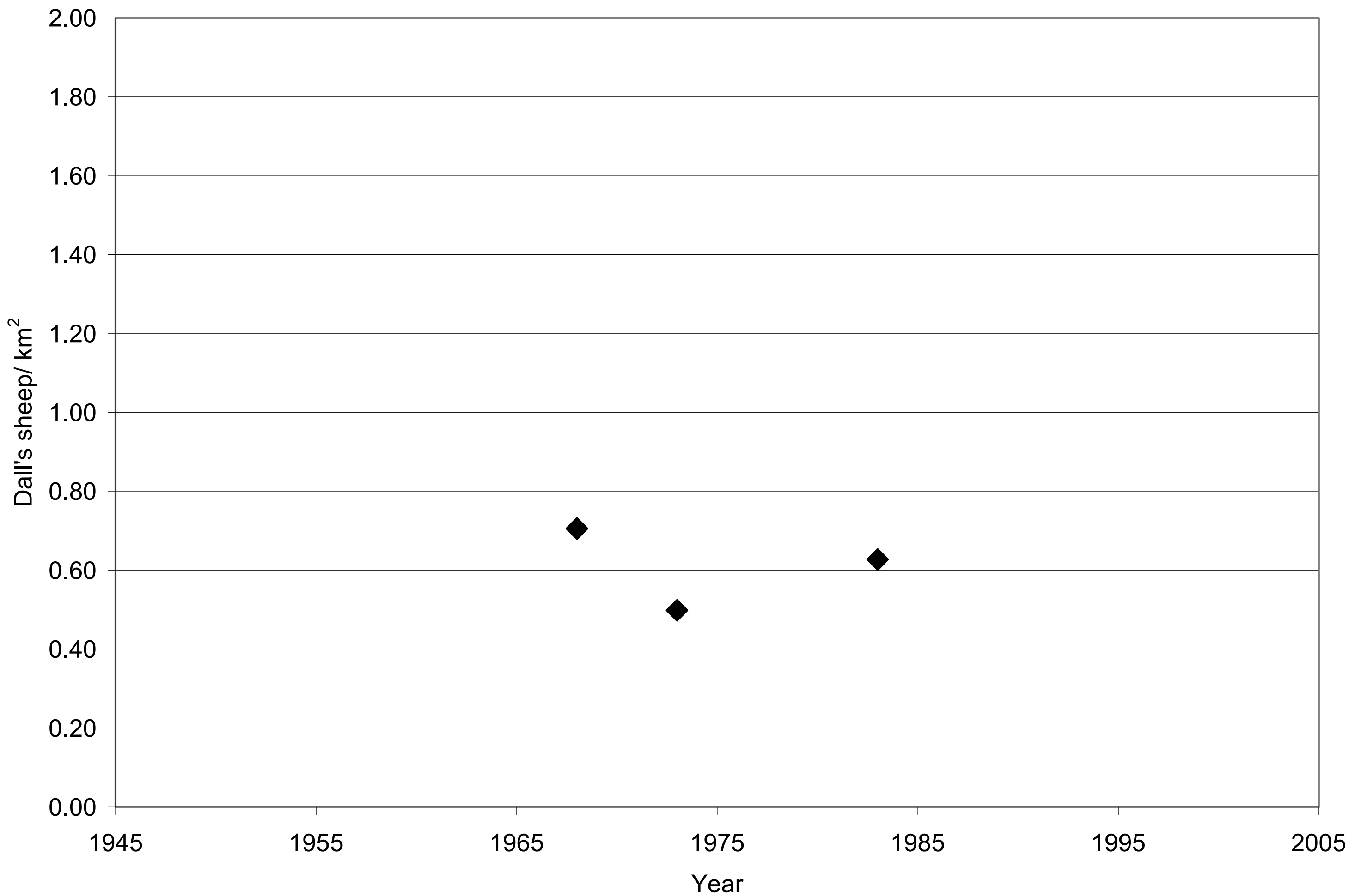

Figure C.14. Dall's sheep densities in survey unit 17, Chitistone, Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Densities were estimated using surface area estimated from a 60m digital elevation model.

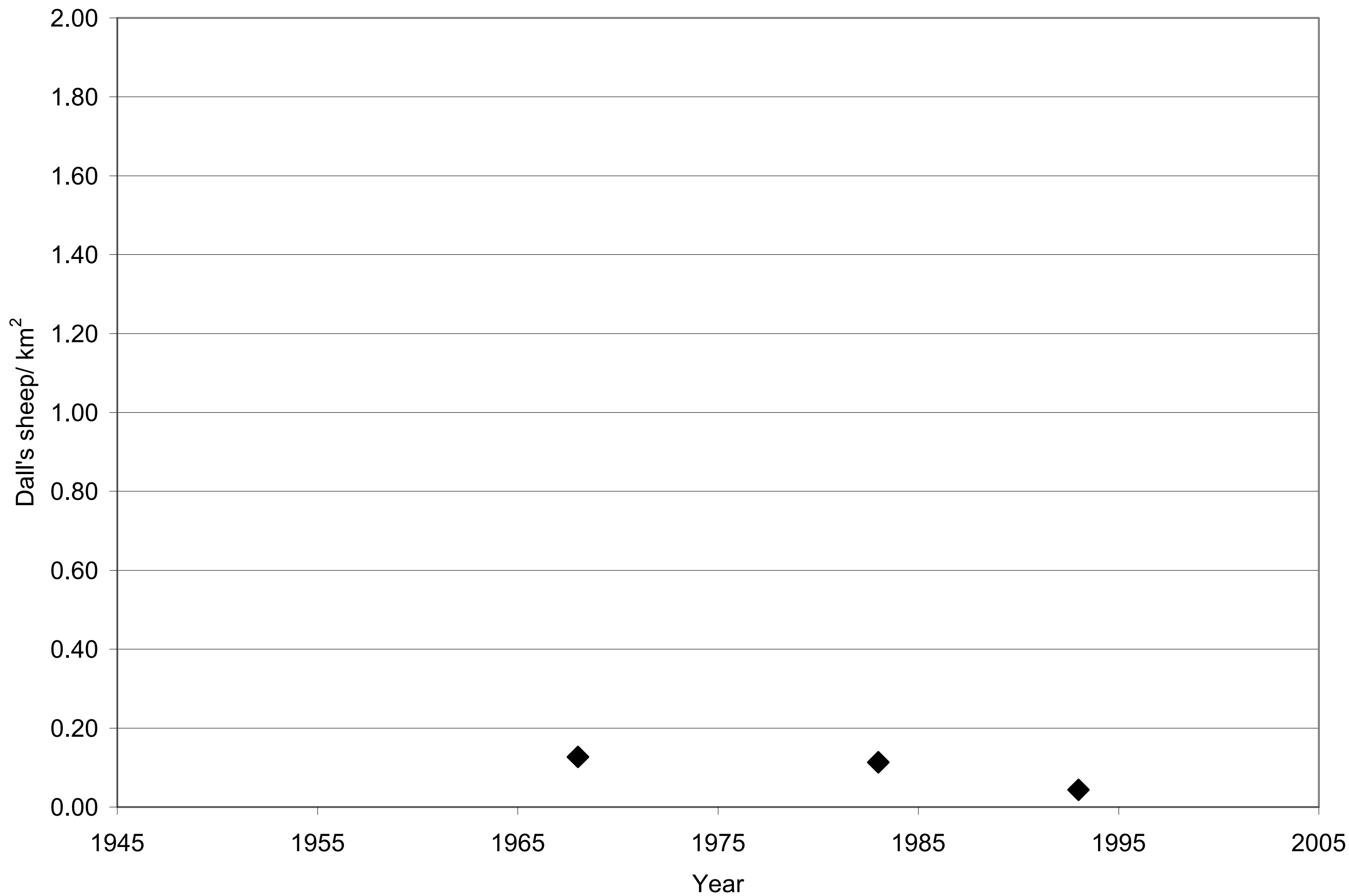

Figure C.15. Dall's sheep densities in survey unit 19, Mount Sulzer, Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Densities were estimated using surface area estimated from a 60m digital elevation model.

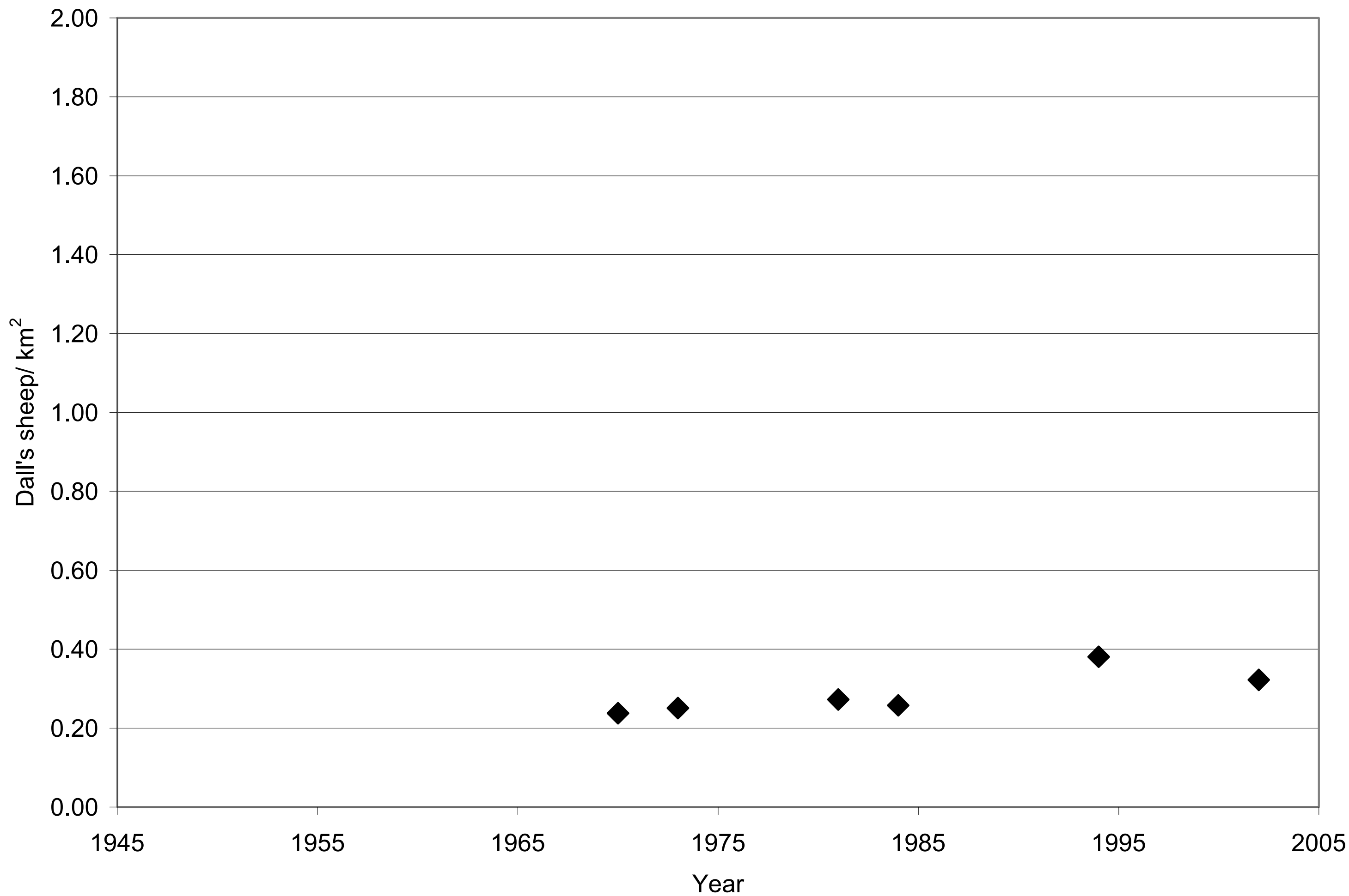

Figure C.16. Dall's sheep densities in survey unit 20, Chititu, Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Densities were estimated using surface area estimated from a 60m digital elevation model.

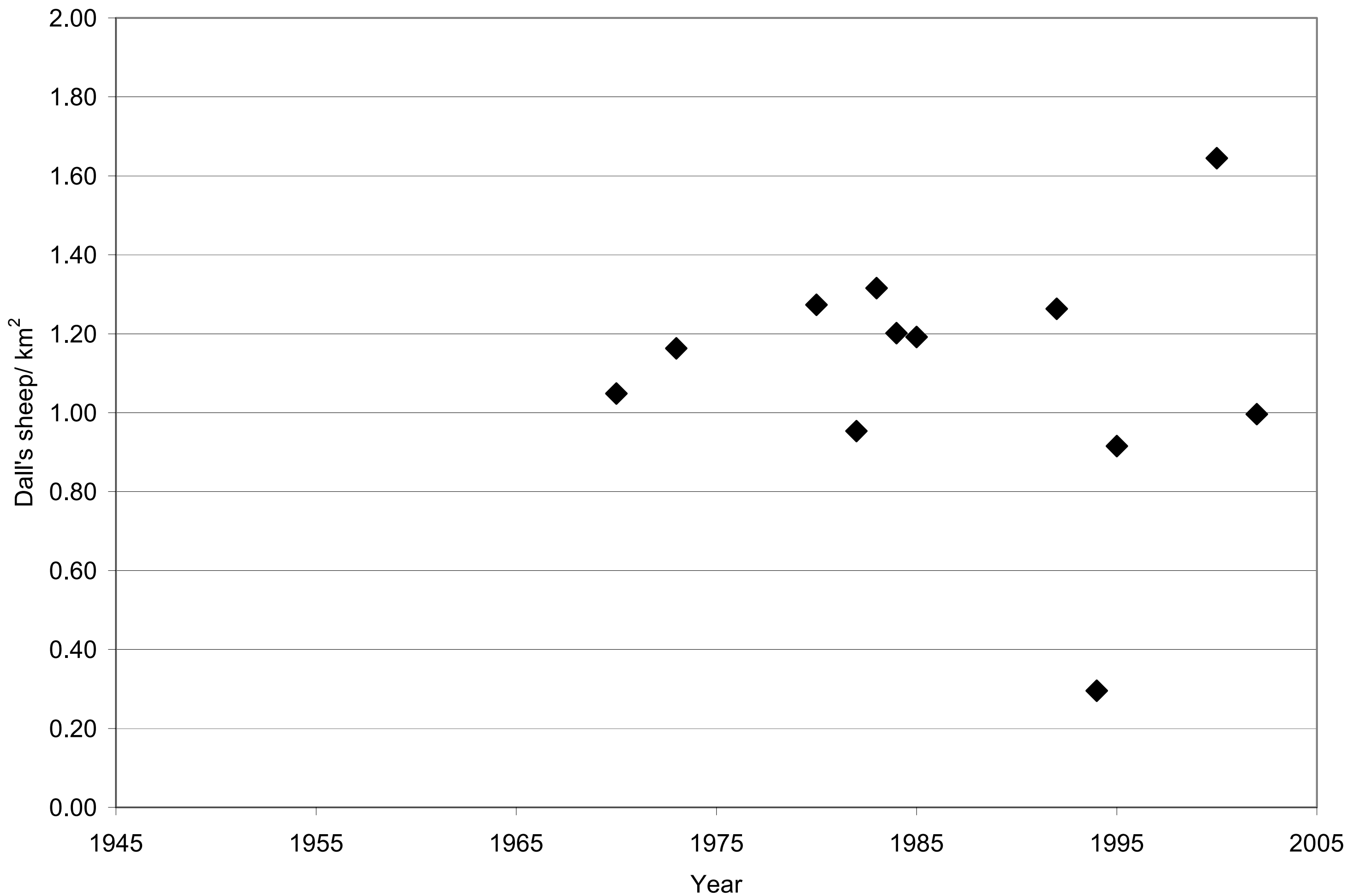

Figure C.17. Dall's sheep densities in survey unit 21, MacColl Ridge, Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Densities were estimated using surface area estimated from a 60m digital elevation model.

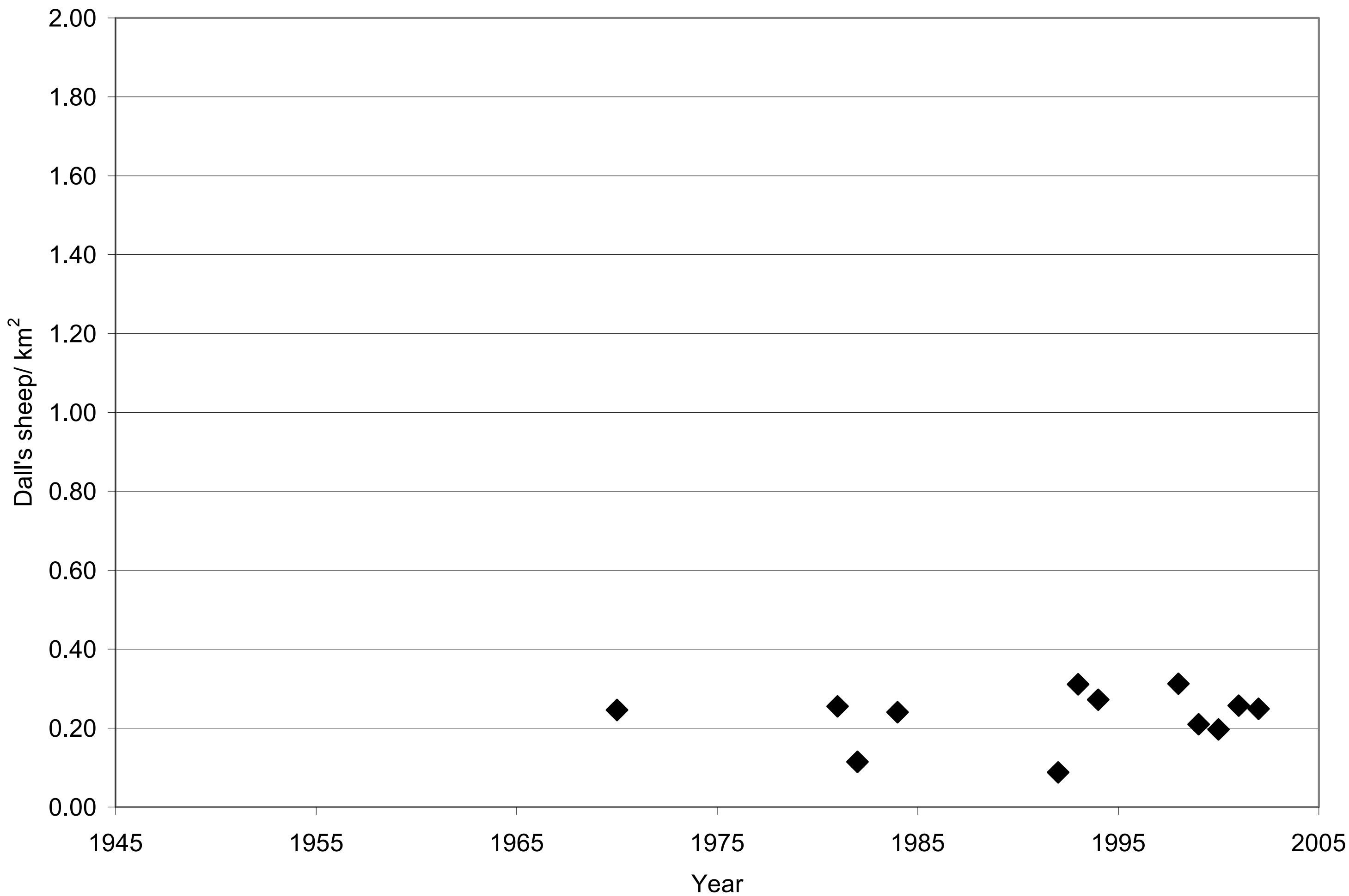

Figure C.18. Dall's sheep densities in survey unit 22, Hawkins Glacier, Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Densities were estimated using surface area estimated from a 60m digital elevation model.

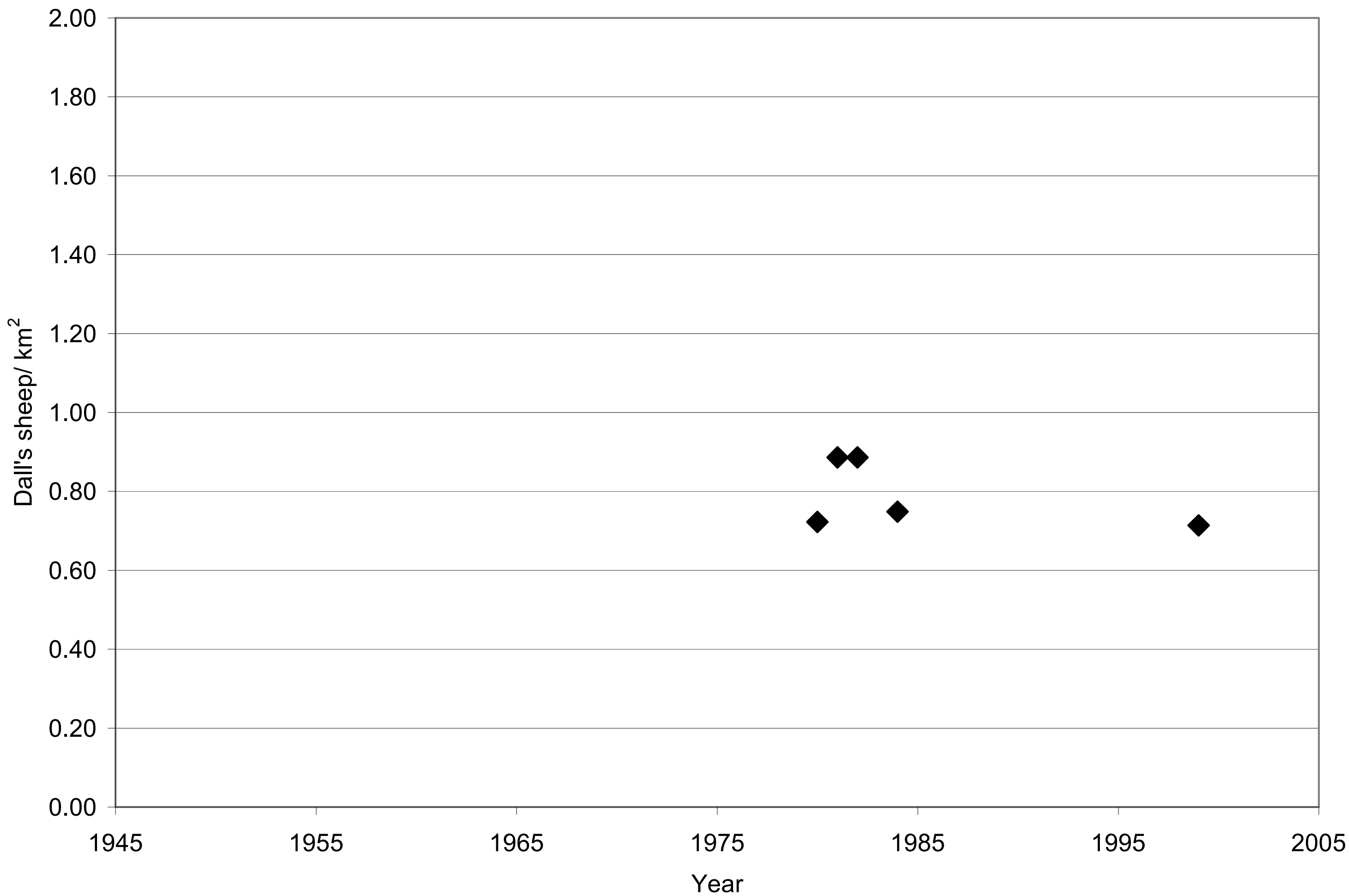

Figure C.19. Dall’s sheep densities in survey unit 23W, Chitina, Preserve, Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Densities were estimated using surface area estimated from a 60m digital elevation model.

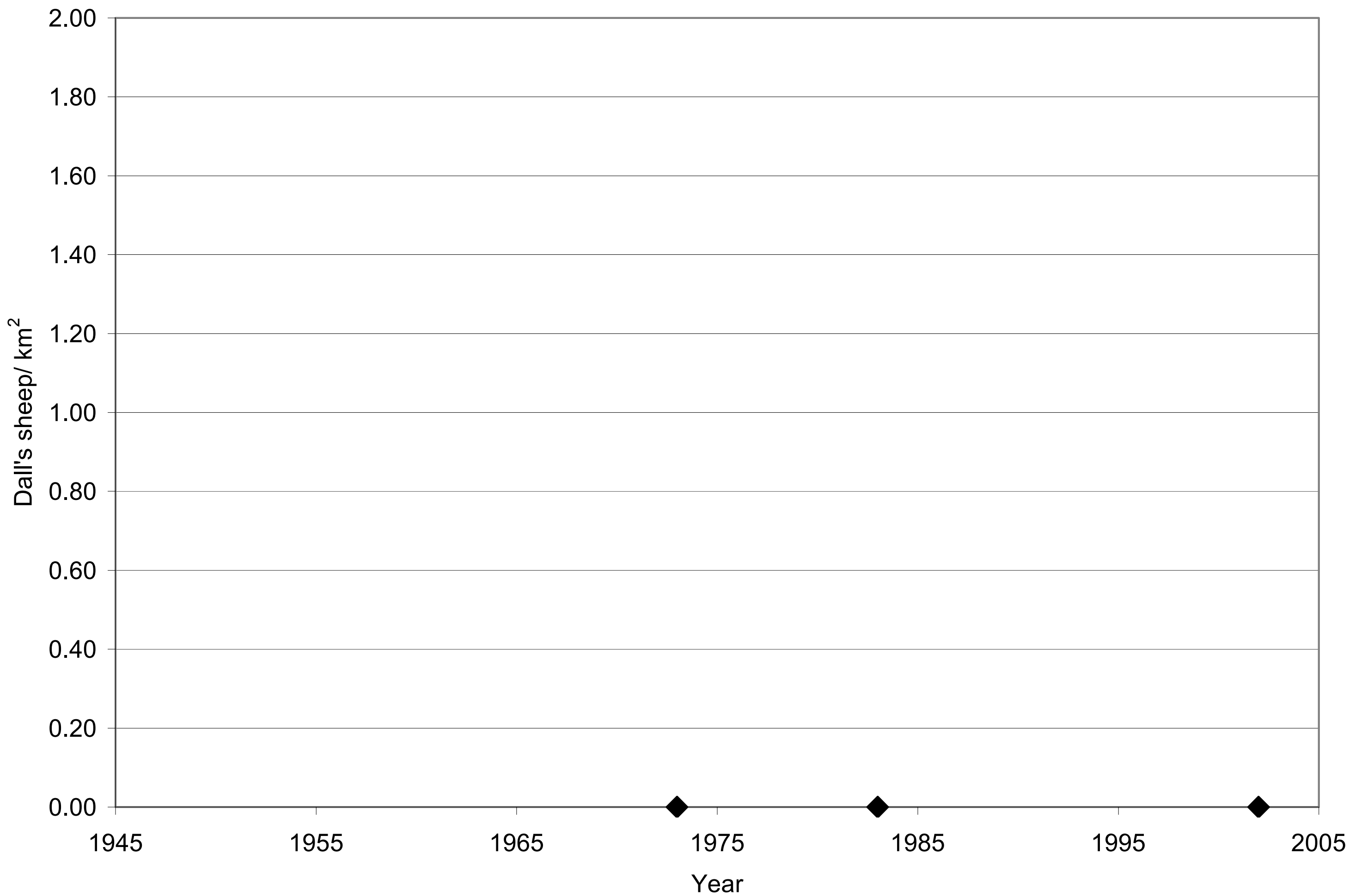

Figure C.20. Dall’s sheep densities in survey unit 26, Hanagita Peak, Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Densities were estimated using surface area estimated from a 60m digital elevation model.

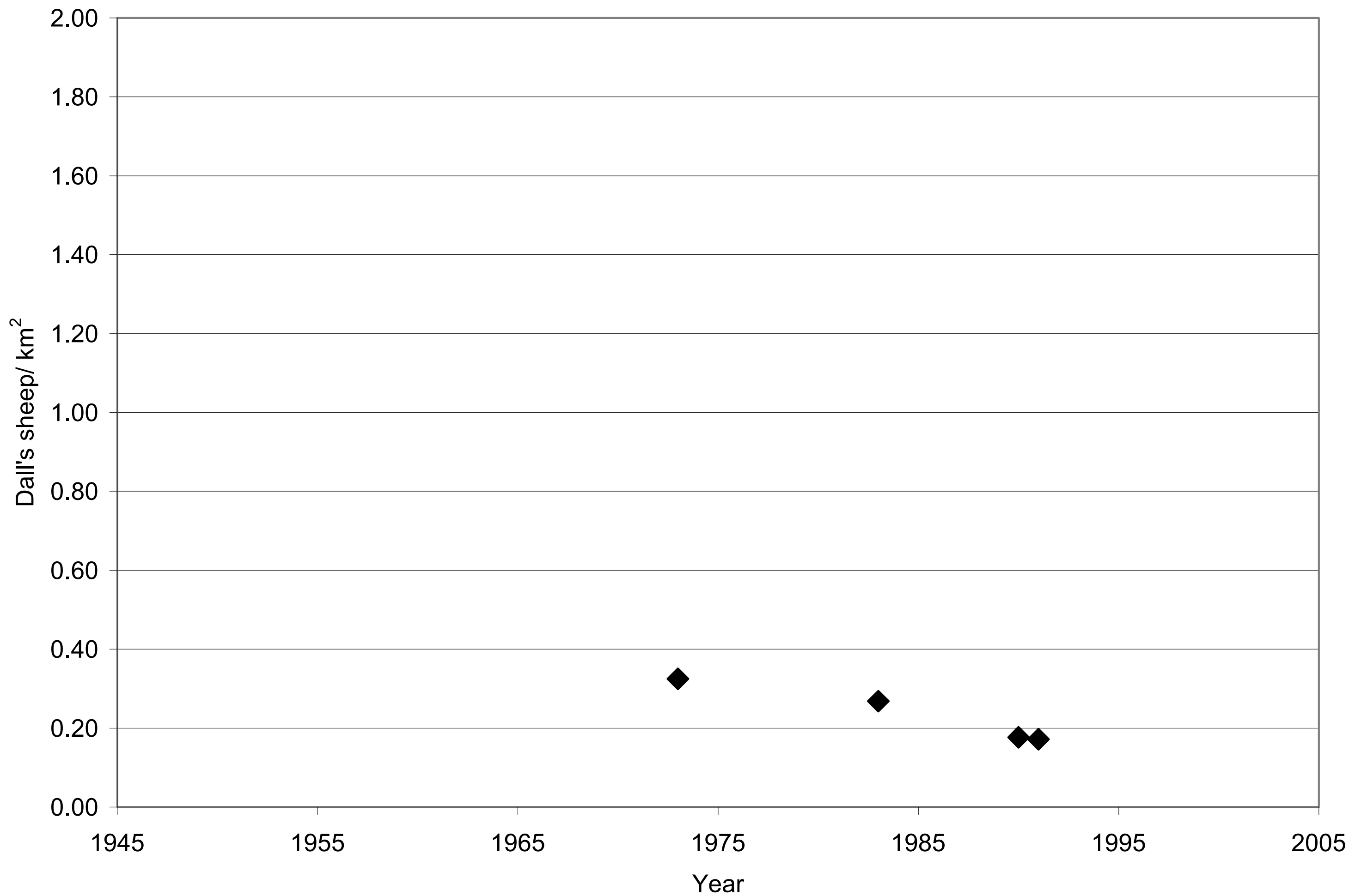

Figure C.21. Dall's sheep densities in survey unit 27, Nelson Mountain, Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Densities were estimated using surface area estimated from a 60m digital elevation model.

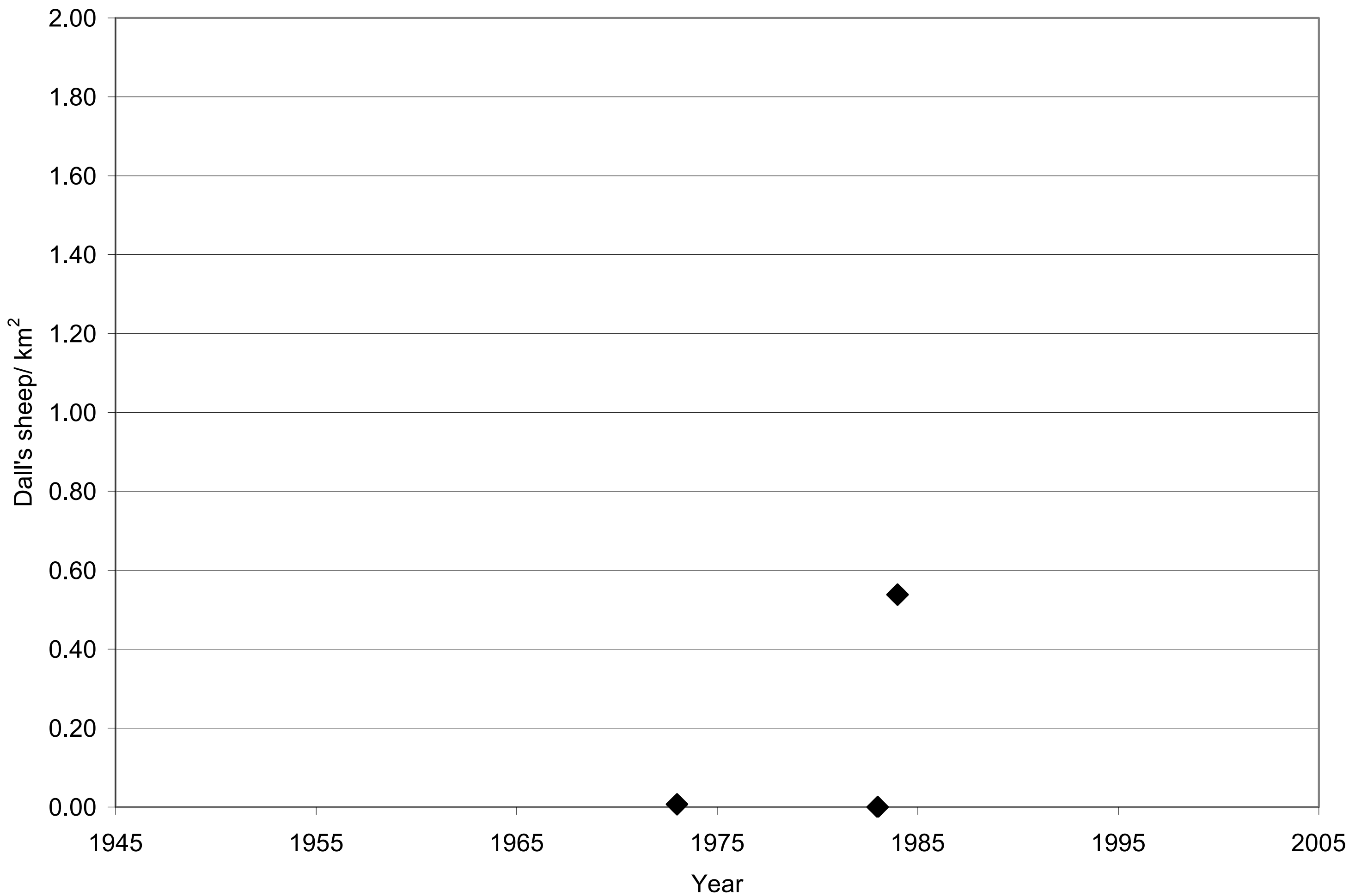

Figure C.22. Dall's sheep densities in survey unit 28, Goodlata Peak, Wrangell-St. Elias National Park and Preserve, Alaska, 1949-2002. Densities were estimated using surface area estimated from a 60m digital elevation model.

APPENDIX D.

Results from nitrogen (Table E.1-E.2) and microhistological (Table E.1) analyses of Dall's sheep fecal pellets from 6 survey units in Wrangell-St. Elias National Park and Preserve, Alaska. Twenty samples of 5 fecal pellets were collected from survey units 9, 12, 20, 21, 22, and, 23W in June and July of 2002. Samples were air dried in paper bags on collection. Rich Kedrowski of the Chemical Nutrition Laboratory, University of Alaska, Fairbanks, AK performed the chemical analysis to estimate nitrogen, neutral detergent fiber, and ash. Nitrogen content was determined by combustion in a LECO auto-analyzer. Microhistological analyses were conducted by the Wildlife Habitat Nutrition Laboratory, University of Washington, Pullman, WA. Proportion of plant composition of fecal pellets was determined at a plant species level using 4 slides per sample at 25 views per slide.

Table D.1. Summary of plant groups and chemical analyses of fecal pellets from 6 Dall's sheep survey units in Wrangell-St. Elias National Park and Preserve, Alaska, 2002.

SU[a]	Percentages in Fecal Pellets								
	GRASS	SEDGE/ RUSH	SHRUB	MOSS	LICHEN	FORB	N[b]	NDF[c]	Ash[d]
9[e]	18.6	57.87	7.1	7.2	2.3	7	0.2	58.76	20.12
12[f]	45.5	6.4	6.8	28.3	7.2	5.8	0.2	57.86	17.79
20[g]	13.1	17.9	11.2	0.7	1.9	55.2	0.2	37.86	19.05
21[h]	32.2	47.6	9.2	4.8	0	6.2	0.2	63.00	42.71
22[i]	16.1	44.2	5.7	8.1	13.3	12.6	0.2	59.69	21.22
23W[j]	37.3	41.3	6.4	3	0	12	0.2	54.84	19.28

a) Aerial survey unit identification number
b) Nitrogen content
c) Neutral detergent fiber content
d) Non-plant material
e) Ptarmigan Lake, sampled 19-22 July 2002
f) Kluvesna Glacier, sampled 1-9 July 2002
g) Chititu Ridge, sampled 30 July – 3 August 2002
h) MacColl Ridge, sampled 15-19 June 2002
i) Hawkins Glacier, sampled 10-14 July 2002
j) Chitina, Preserve, sampled 6-9 August 2002

Table D.2. Species of plant fragments in fecal pellets of Dall's sheep (*Ovis dalli*) in Wrangell-St. Elias National Park and Preserve, Alaska. Pellets were collected in 2002.

Plants	Survey Units					
	9[a]	12[b]	20[c]	21[d]	22[e]	23[f]
Agrostis	1.9	3.4	1.9	2.4	1.8	3.7
Alopecurus	4.9	6.0		2.9	2.5	5.7
Calamagrostis	3.0	22.2	2.6	17.1	3.2	21.6
Deschampsia	1.1		1.9			
Festuca		3.0		3.1	2.5	3.3
Hierochloe						
Poa	4.5	9.0	4.1	6.7	5.0	2.3
Unkown Grasses	3.2	1.9	2.6		1.1	0.7
Total Grasses:	19	45.5	13.1	32.2	16.1	37.3
Carex aquatilis	17		0.4	9.4	14.5	7.6
Carex	22	3.4	9.7	13.0	7.8	20.6
Eriophorum	6.7	0.8	4.1	10.1	3.5	1.7
Juncus	10	1.1	3.0	11.8	14.9	5.0
Kobresia	1.3	1.1	0.7	1.9	2.1	1.7
Luzula	1.1			1.4	1.4	4.7
Total Sedge/Rush:	58	6.4	17.9	47.6	44.2	41.3
Arctostaphylos stem			5.2			
Betula stem		4.1			1.8	
Cassiope leaf				1.9	1.8	
Dryas leaf	0.9		0.7	5.1		3.0
Dryas stem			1.5			
Salix leaf	2.6		3.8	0.5		1.0
Salix stem	3.2	2.7		1.0	1.4	0.7
Salix catkin					0.7	
Unknown shrubs	0.4			0.7		1.7
Total Shrubs:	7.1	6.8	11.2	9.2	5.7	6.4

Table D.2. *Continued.* Species of plant fragments in fecal pellets of Dall's sheep (*Ovis dalli*) in Wrangell-St. Elias National Park and Preserve, Alaska. Pellets were collected in 2002. *(Continued on following page)*

Plants	Survey Units					
	9[a]	12[b]	20[c]	21[d]	22[e]	23[f]
Aulacomium moss				4.8		
Classic moss	6.2	20.0	0.7		6.0	0.7
Polytrichum moss	0.6	8.3			2.1	2.3
Sphagnum moss	0.4					
Total Moss:	7.2	28.3	0.7	4.8	8.1	3.0
Alectoria/Bryoria/Usnea	1.1	0.4	0.4			
Cetraria/Dactilina		1.1			0.7	
Cladonia/Cladina	0.6	3.4	1.1		3.5	
Stereocaulon			0.4		0.3	
Peltigera type (foliose)	0.6	2.3			8.8	
Total Lichens:	2.3	7.2	1.9	0.0	13.3	0.0
Astragalus			1.5	0.5	0.3	
Epilobium			18.3		1.1	1.7
Equisetum			1.5	0.7	2.5	
Hedysarum						1.3
Legume pod			5.6			4.7
Lupinus	0.9	1.1	8.8	0.3	1.4	1.3
Myosotis			3.4			
Oxytropis			1.5		0.3	
Penstemon					1.1	1.3
Phacelia			0.4	0.3		
Phlox			3.4		2.5	
Polygonum			0.7			
Potentilla	3.1	2.8	4.9	3.2	0.2	1.0
Stellaria					0.7	
Unknown Forbs	3.0	1.9	5.2	1.2	2.5	0.7
Total Forbs:	7.0	5.8	55.2	6.2	12.6	12.0

a) Survey unit 9, Ptarmigan Lake, sampled 19-22 July 2002
b) Survey unit 12, Kluvesna Glacier, sampled 1-9 July 2002
c) Survey unit 20, Chititu Ridge, sampled 30 July-3 August 2002
d) Survey unit 21, MacColl Ridge, sampled 15-19 June 2002

Table D.2. *Continued.* Species of plant fragments in fecal pellets of Dall's sheep (*Ovis dalli*) in Wrangell-St. Elias National Park and Preserve, Alaska. Pellets were collected in 2002.

e) Survey unit 22, Hawkins Glacier, sampled 10-14 July 2002
f) Survey unit 23W, Chitina, Preserve, sampled 6-9 August 2002

APPENDIX E.

Fixed wing aerial census survey data for Dall's sheep (*Ovis dalli*) in Wrangell-St. Elias National Park and Preserve, Alaska 1949-2002. All surveys were flown between 14 June and 8 August 1949-2002 with the exception of 2 surveys in 1967 which were flown 30 November and 1 December with an average flight time of 5 hours. More complete information is on file at the park.

Table E.1. Aerial survey data for Dall's sheep, 1949-2002, in Wrangell-St. Elias National Park and Preserve, Alaska. *Continued on following pages.*

Count Area	Year	# Ewes	# Lambs	# Rams	# UnID Sheep	Total # Sheep	Surface Area km^2	Density (sheep / km^2)	Lamb: 100 Ewe	Agency	Observers	Pilot
ca01	1971	555	137	110	212	1014	1292.30	0.85	25	ADF&G Tok	Jennings	
ca01	1973	707	100	265		1072	1292.30	0.90	14	ADF&G Tok	Jennings	
ca01	1980	754	356	307	132	1549	1292.30	1.30	47	ADF&G Tok	Kelleyhouse & Grangaard	
ca01	1997	692	196	167	0	1055	1292.30	0.88	28	ADF&G Tok	Gardner	Zaczkowski
ca01	2002	575	123	316	3	1017	1292.30	0.85	21	WRST NP/P	Reid	McMahon
ca02	1973	166	38	16		220	1662.41	0.14	23	ADF&G Glennallen	Harkness	
ca02	2002	105	38	64	0	207	1662.41	0.13	36	WRST NP/P	Reid	McMahon
ca03	1973	1283	307	317		1907	2361.96	0.85	24	ADF&G Tok	Smith	
ca03	1990	453	19	99		571	2361.96	0.26	4	WRST NP/P	McDonald, Kern, Strickland, Taylor, & Mullen	Hannah
ca03	1991				1354	1354	2361.96	0.61		WRST NP/P	Strickland	Hannah
ca03	1998	317	105	84	0	506	2361.96	0.23	33	WRST NP/P	Grangaard	Zaczkowski
ca04W	1973	428	76	195		699	1292.44	0.54	18	ADF&G Tok	Jennings	
ca04W	1998	153	47	45	0	245	1292.44	0.19	31	WRST NP/P	Grangaard	Zaczkowski
ca05E	1974		62	415	16	493	429.21	1.15		ADF&G Tok	Jennings	
ca05E	1991				352	352	429.21	0.82		WRST NP/P	Strickland	Hannah
ca05E	2001	210	27	139	0	376	429.21	0.88	13	ADF&G Tok	Gardner	Zaczkowski
ca05W	2001	289	60	135	0	484	648.31	0.75	21	ADF&G Tok	Gardner	Zaczkowski
ca07E	1974	125	6	42	9	182	800.31	0.24	5	ADF&G Tok	Jennings	

Table E.1. *Continued.* Aerial survey data for Dall's sheep, 1949-2002, in Wrangell-St. Elias National Park and Preserve, Alaska. *Continued on following pages.*

Count Area	Year	# Ewes	# Lambs	# Rams	# UnID Sheep	Total # Sheep	Surface Area km²	Density (sheep / km²)	Lamb: 100 Ewe	Agency	Observers	Pilot
ca07E	2001	148	32	113	0	293	800.31	0.39	22	ADF&G Tok	Gardner	Zaczkowski
ca07E	2002	380	112	217		709	800.31	0.95	29	ADF&G Tok	Gardner	Zaczkowski
ca07W	1974	205	59	70	12	346	786.96	0.48	29	ADF&G Tok	Jennings	
ca07W	1990	197	75	103	148	523	786.96	0.73	38	WRST NP/P	McDonald, Kern, Strickland, Taylor, & Mullen	Hannah
ca07W	1991				437	437	786.96	0.61		WRST NP/P	Strickland	Hannah
ca07W	1998	373	113	132	0	618	786.96	0.86	30	WRST NP/P	Mitchell	McMahon
ca07W	1999	336	127	102		565	786.96	0.79	38	WRST NP/P	Yates, Busteed, & Jansen	McMahon/ Hannah
ca09	1949				228	228	895.98	0.27		FWS, Tetlin	Scott	
ca09	1962				549	549	895.98	0.64		ADF&G Tok	Jones	
ca09	1967				663	663	895.98	0.77		ADF&G Tok	Jones	
ca09	1968	410	123	263	24	820	895.98	0.96	30	ADF&G Tok	Jennings	Nichols
ca09	1975	259	138	193	270	860	895.98	1.00	53	ADF&G Tok	?	
ca09	1977	282	122	75	31	510	895.98	0.59	43	ADF&G Tok	?	
ca09	1978	435	136	89	6	666	895.98	0.78	31	ADF&G Tok	Kelleyhouse & Warbelow	
ca09	1981	682	249	246	0	1177	895.98	1.37	37	ADF&G Tok	Grangaard & Warbelow	

Table E.1. *Continued.* Aerial survey data for Dall's sheep, 1949-2002, in Wrangell-St. Elias National Park and Preserve, Alaska. *Continued on following pages.*

Count Area	Year	# Ewes	# Lambs	# Rams	# UnID Sheep	Total # Sheep	Surface Area km^2	Density (sheep / km^2)	Lamb: 100 Ewe	Agency	Observers	Pilot
Ca09	1992	221	91	130	224	666	895.98	0.78	41	WRST NP/P	Strickland, Galipeau, Russell, & Jenkins	McMahon/ Hannah
ca09	1998	380	118	157	0	655	895.98	0.76	31	WRST NP/P	Mitchell	McMahon
ca09	1999	500	145	183		828	895.98	0.97	29	WRST NP/P	Yates, Busteed, & Jansen	McMahon/ Hannah
ca09	2002	358	125	234	18	735	895.98	0.86	35	ADF&G Tok	Gardner	Zaczkowski
ca10	1973	150	23	35		208	726.23	0.30	15	ADF&G Glennallen	Harkness	
ca10	1981	107	59	35		201	726.23	0.29	55	ADF&G Glennallen	Tobey	Bunch
ca10	1990	111	25	11		147	726.23	0.21	23	WRST NP/P	McDonald, Kern, Strickland, Taylor, & Mullen	Hannah
ca10	1991				47	47	726.23	0.07		WRST NP/P	Strickland	Hannah
ca10	1992			8	69	77	726.23	0.11		WRST NP/P	Strickland	Hannah
ca11	1967	28	5	46	129	208	688.22	0.32	18	ADF&G Tok	Erickson	Nichols
ca11	1973	253	47	107		407	688.22	0.62	19	ADF&G Glennallen	Steen	
ca11	1982	359	126	72		557	688.22	0.85	35	ADF&G Glennallen	Tobey	Bunch
ca11	1984	283	60	71		414	688.22	0.63	21	ADF&G Glennallen	Tobey	Bunch
ca11	1987	330	106	123		559	688.22	0.85	32	ADF&G Glennallen	Tobey	Bunch
ca11	1990	231	78	52		361	688.22	0.55	34	ADF&G Glennallen	Tobey	McMahon

Table E.1. *Continued.* Aerial survey data for Dall's sheep, 1949-2002, in Wrangell-St. Elias National Park and Preserve, Alaska. *Continued on following pages.*

Count Area	Year	# Ewes	# Lambs	# Rams	# UnID Sheep	Total # Sheep	Surface Area km^2	Density (sheep / km^2)	Lamb: 100 Ewe	Agency	Observers	Pilot
ca11	1993	172	35	61		268	688.22	0.41	20	ADF&G Glennallen	Tobey	McMahon
ca11	1994	197	85	39		321	688.22	0.49	43	ADF&G Glennallen	Tobey	McMahon
ca11	1995	237	83	27		347	688.22	0.53	35	ADF&G Glennallen	Tobey	McMahon
ca11	1996	169	46	39		254	688.22	0.39	27	ADF&G Glennallen	Tobey	McMahon
ca11	1997	198	50	49		297	688.22	0.45	25	ADF&G Glennallen	Tobey	McMahon
ca11	1998	109	26	49		184	688.22	0.28	24	ADF&G Glennallen	Tobey	McMahon
ca11	1999	160	44	52		256	688.22	0.39	28	ADF&G Glennallen	Tobey	McMahon
ca11	2000	161	38	40		239	688.22	0.37	24	ADF&G Glennallen	Scotten & Tobey	McMahon
ca11	2001	147	32	43		222	688.22	0.34	22	ADF&G Glennallen	Scotten & Tobey	McMahon
ca11	2002	100	27	48		175	688.22	0.27	27	ADF&G Glennallen	Scotten	McMahon
ca12	1967	15	4	29	46	94	1083.69	0.09	27	ADF&G Tok	Erickson	Nichols
ca12	1973		47	51	98	196	1083.69	0.20		ADF&G Glennallen	Steen	
ca12	1981	359	129	78		566	1083.69	0.57	36	ADF&G Glennallen	Tobey	Bunch
ca12	1982	341	64	109		514	1083.69	0.51	19	ADF&G Glennallen	Tobey	Bunch
ca12	1983	341	64	109		514	1083.69	0.51	19	ADF&G Glennallen	Tobey	Bunch
ca12	1984	290	68	132		490	1083.69	0.49	23	ADF&G Glennallen	Tobey	Bunch
ca12	1993	426	39	103		568	1083.69	0.57	9	ADF&G Glennallen	Tobey	McMahon
ca12	1996	346	105	150		601	1083.69	0.60	30	ADF&G Glennallen	Tobey	McMahon
ca12	1998	242	75	132		449	1083.69	0.45	31	ADF&G Glennallen	Tobey	McMahon
ca12	1999	250	59	147		456	1083.69	0.46	24	ADF&G Glennallen	Tobey	McMahon
ca12	2000	173	31	125		329	1083.69	0.33	18	ADF&G Glennallen	Scotten & Tobey	McMahon
ca12	2001	185	26	77		288	1083.69	0.29	14	ADF&G Glennallen	Scotten & Tobey	McMahon

Table E.1. *Continued.* Aerial survey data for Dall's sheep, 1949-2002, in Wrangell-St. Elias National Park and Preserve, Alaska. *Continued on following pages.*

Count Area	Year	# Ewes	# Lambs	# Rams	# UnID Sheep	Total # Sheep	Surface Area km^2	Density (sheep / km^2)	Lamb: 100 Ewe	Agency	Observers	Pilot
ca13	1984	85	19	46		150	670.79	0.25	22	ADF&G Glennallen	Tobey	Bunch
ca13	1991				277	277	670.79	0.45		WRST NP/P	Strickland	Hannah
ca13	1992	264	48	122		434	670.79	0.71	18	WRST NP/P	Galipeau, Russell, & Jenkins	Barnes
ca13	1995	207	56	78	1	342	670.79	0.56	27	WRST NP/P	Jenkins & Barten, & VanBuskirk	McMahon/ Bunch
ca13	1999	226	71	72		369	670.79	0.61	31	ADF&G Glennallen	Scotten	McMahon
ca14	1950			0	98	98	114.65	0.93		ADF&G Glennallen	Scott	
ca14	1973	112	42	39		193	114.65	1.84	38	ADF&G Glennallen	Steen	
ca14	1981	142	60	7		209	114.65	1.99	42	ADF&G Glennallen	Tobey	Bunch
ca14	1990	40	23	13	73	149	114.65	1.42	58	FWS Tetlin	Strickland	Hannah
ca14	1991				137	137	114.65	1.31		FWS Tetlin	Strickland	Hannah
ca14	1993	85	18	21		124	114.65	1.18	21	ADF&G Glennallen	Tobey	McMahon
ca14	1994	56	6	17		79	114.65	0.75	11	ADF&G Glennallen	Tobey	McMahon
ca14	1995	36	14	15	14	79	114.65	0.75	39	WRST NP/P	Jenkins & Barten, & VanBuskirk	McMahon/ Bunch
ca14	1999	57	19	15		91	114.65	0.87	33	ADF&G Glennallen	Scotten	McMahon
ca14	2001	43	6	11		60	114.65	0.57	14	ADF&G Glennallen	Scotten & Tobey	McMahon
ca14	2002	39	11	0		50	114.65	0.48	28	ADF&G Glennallen	Scotten	McMahon

Table E.1. *Continued.* Aerial survey data for Dall's sheep, 1949-2002, in Wrangell-St. Elias National Park and Preserve, Alaska. *Continued on following pages.*

Count Area	Year	# Ewes	# Lambs	# Rams	# UnID Sheep	Total # Sheep	Surface Area km^2	Density (sheep / km^2)	Lamb: 100 Ewe	Agency	Observers	Pilot
ca15	1973	27	10	11		48	1052.02	0.05	37	ADF&G Glennallen	Steen	
ca15	1981	97	27	35		159	1052.02	0.16	28	ADF&G Glennallen	Tobey	Bunch
ca15	1995	69	18	7	7	101	1052.02	0.10	26	WRST NP/P NP/P	Jenkins & Barten, & VanBuskirk	McMahon/ Bunch
ca15	1999	99	26	24		149	1052.02	0.15	26	ADF&G Glennallen	Tobey	McMahon
ca16	1968	96	28	5		129	964.24	0.14	29	ADF&G Tok	Jennings	Nichols
ca16	1973	83	21	19	101	224	964.24	0.25	25	ADF&G Glennallen	Irvine	Smith
ca16	1983	170	67	47		284	964.24	0.31	39	ADF&G Glennallen	Tobey	Bunch
ca16	1990	8	5	11	219	243	964.24	0.27	63	WRST NP/P	McDonald, Kern, Strickland, Taylor, & Mullen	Hannah
ca16	1991				161	161	964.24	0.18		WRST NP/P	Strickland	Hannah
ca16	1992	194	66	43		303	964.24	0.33	34	ADF&G Glennallen	Tobey	McMahon
ca17	1968	225	48	44		317	481.45	0.71	21	ADF&G Tok	Jennings	Nichols
ca17	1973	184	21	19		224	481.45	0.50	11	ADF&G Glennallen	Irvine	Smith
ca17	1983	75	13	26		114	481.45	0.25	17	WRST NP/P NP/P	Mullen	Bunch
ca17	1983	187	50	45		282	481.45	0.63	27	ADF&G Glennallen	Tobey	Bunch
ca18	1968	190	52	84	9	335	1105.87	0.32	27	ADF&G Tok	Jennings	Nichols
ca18	1983	336	127	82	1	546	1105.87	0.52	38	WRST NP/P	Jansen	McMahon
ca18	1983	146	28	83		257	1105.87	0.25	19	ADF&G Glennallen	Tobey	McMahon

Table E.1. *Continued.* Aerial survey data for Dall's sheep, 1949-2002, in Wrangell-St. Elias National Park and Preserve, Alaska. *Continued on following pages.*

Count Area	Year	# Ewes	# Lambs	# Rams	# UnID Sheep	Total # Sheep	Surface Area km²	Density (sheep / km²)	Lamb: 100 Ewe	Agency	Observers	Pilot
ca19	1968	89	12	42		143	1217.22	0.13	13	ADF&G Tok	Jennings	Nichols
ca19	1983	62	34	32		128	1217.22	0.11	55	ADF&G Glennallen	Tobey	Bunch
ca19	1993	40	6	2	1	49	1217.22	0.04	15	WRST NP/P	Jenkins	Hannah
ca20	1970	86	35	22		143	661.67	0.24	41	ADF&G Glennallen	Johnson	
ca20	1973	92	28	31		151	661.67	0.25	30	ADF&G Glennallen	Irvine	Smith
ca20	1981	80	38	46		164	661.67	0.27	48	ADF&G Glennallen	Tobey	Bunch
ca20	1984	105	23	27		155	661.67	0.26	22	ADF&G Glennallen	Tobey	Bunch
ca20	1994	88	23	34	2	147	661.67	0.24	26	WRST NP/P	deBruyn	Hannah
ca20	2002	107	33	54	0	194	661.67	0.32	31	WRST NP/P	Reid	McMahon
ca21	1970	114	60	46		220	220.70	1.05	53	ADF&G Glennallen	Johnson	
ca21	1973	144	45	55		244	220.70	1.16	31	ADF&G Glennallen	Irvine	Smith
ca21	1980	190	58	19		267	220.70	1.27	31	ADF&G Glennallen	Tobey	Bunch
ca21	1982	151	18	22	9	200	220.70	0.95	12	WRST NP/P	Strickland	Hannah
ca21	1982	187	69	49		305	220.70	1.45	37	ADF&G Glennallen	Tobey	Bunch
ca21	1983	186	39	51		276	220.70	1.32	21	ADF&G Glennallen	Tobey	Bunch
ca21	1984	157	43	52		252	220.70	1.20	27	ADF&G Glennallen	Tobey	Bunch
ca21	1985	183	41	26		250	220.70	1.19	22	ADF&G Glennallen	Tobey	Bunch
ca21	1992			22	243	265	220.70	1.26		WRST NP/P	Strickland	Hannah
ca21	1994	49		8	5	62	220.70	0.30		WRST NP/P	Strickland	Hannah
ca21	1995	36	19	0	137	192	220.70	0.92	53	ADF&G Glennallen	Tobey	McMahon
ca21	2000	188	26	122	9	345	220.70	1.64	14	WRST NP/P	Mitchell	Hannah
ca21	2002	121	42	46	0	209	220.70	1.00	35	WRST NP/P	Reid	McMahon

Table E.1. *Continued.* Aerial survey data for Dall's sheep, 1949-2002, in Wrangell-St. Elias National Park and Preserve, Alaska. *Continued on following pages.*

Count Area	Year	# Ewes	# Lambs	# Rams	# UnID Sheep	Total # Sheep	Surface Area km^2	Density (sheep / km^2)	Lamb: 100 Ewe	Agency	Observers	Pilot
ca22	1970	131	61	48		240	1072.21	0.25	47	ADF&G Glennallen	Johnson	
ca22	1981	143	51	55		249	1072.21	0.25	36	ADF&G Glennallen	Tobey	Bunch
ca22	1982		34	16	62	112	1072.21	0.11		ADF&G Glennallen	Tobey	Bunch
ca22	1984	125	43	67		235	1072.21	0.24	34	ADF&G Glennallen	Tobey	Bunch
ca22	1992	18	4	5	59	86	1072.21	0.09	22	WRST NP/P	Strickland	Hannah
ca22	1993	190	63	51		304	1072.21	0.31	33	ADF&G Glennallen	Tobey	McMahon
ca22	1994		23	5	70	98	1072.21	0.10		ADF&G Glennallen	Tobey	Bunch
ca22	1994		7	20	52	79	1072.21	0.08		ADF&G Glennallen	Tobey	Ellis
ca22	1994		39	24	186	249	1072.21	0.25		ADF&G Glennallen	Tobey	Bunch
ca22	1998	317	45	139	14	515	1072.21	0.53	14	WRST NP/P	Mitchell	Hannah
ca22	1998	213	47	45	0	305	1072.21	0.31	22	WRST NP/P	Mitchell	Hannah
ca22	1999	179	66	58		303	1072.21	0.31	37	WRST NP/P	Yates, Busteed, & Jansen	McMahon/ Hannah
ca22	1999	143	16	46		205	1072.21	0.21	11	ADF&G Glennallen	Tobey	McMahon
ca22	2000	143	16	28	5	192	1072.21	0.20	11	WRST NP/P	Mitchell	Hannah
ca22	2001	176	20	55	0	251	1072.21	0.26	11	ADF&G Glennallen	Scotten	McMahon
ca22	2002	142	45	56		243	1072.21	0.25	32	ADF&G Glennallen	Scotten	McMahon
ca23E	1983	26	7	46		79	544.30	0.16	27	ADF&G Glennallen	Tobey	Bunch
ca23W	1980	158	49	40		247	388.11	0.72	31	ADF&G Glennallen	Tobey	Bunch
ca23W	1981	194	66	43		303	388.11	0.89	34	ADF&G Glennallen	Tobey	Bunch
ca23W	1982	194	66	43		303	388.11	0.89	34	ADF&G Glennallen	Tobey	Bunch
ca23W	1984	168	41	47		256	388.11	0.75	24	ADF&G Glennallen	Tobey	Bunch

Table E.1. *Continued.* Aerial survey data for Dall's sheep, 1949-2002, in Wrangell-St. Elias National Park and Preserve, Alaska.

Count Area	Year	# Ewes	# Lambs	# Rams	# UnID Sheep	Total # Sheep	Surface Area km^2	Density (sheep / km^2)	Lamb: 100 Ewe	Agency	Observers	Pilot
ca23W	1999	142	45	57		244	388.11	0.71	32	ADF&G Glennallen	Tobey	McMahon
ca24	1983	56	23	19		98	598.44	0.18	41	ADF&G Glennallen	Tobey	Bunch
ca25	1973				48	48	1150.21	0.05		ADF&G Glennallen	Harkness	
ca25	1983	25	8	8		41	1150.21	0.04	32	WRST NP/P	Mullen & Cella	Bunch
ca26	1973	0	0	0	0	0	1249.61	0.00		ADF&G Glennallen	Steen	
ca26	1983	0	0	0	0	0	1249.61	0.00		WRST NP/P	Mullen & Cella	Bunch
ca26	2002	0	0	0	0	0	1249.61	0.00		WRST NP/P	Reid	McMahon
ca27	1973		21	17	100	138	452.92	0.32		ADF&G Glennallen	Steen	
ca27	1983	75	13	26		114	452.92	0.27	17	WRST NP/P	Mullen	Bunch
ca27	1990	38	3	34		75	452.92	0.18	8	WRST NP/P	McDonald, Kern, Strickland, Taylor, & Mullen	Hannah
ca27	1991				73	73	452.92	0.17		WRST NP/P	Strickland	Hannah
ca28	1973			2	4	6	906.73	0.01		ADF&G Glennallen	Steen	
ca28	1983	0	0	0		0	906.73	0.00		WRST NP/P	Mullen & Cella	Bunch
ca28	1984		64	49	341	454	906.73	0.54		ADF&G Glennallen	Tobey	Bunch
ca31	1990	15	5	4		24	1190.71	0.02	33	WRST NP/P	McDonald, Kern, Strickland, Taylor, & Mullen	Hannah
ca31	1991				27	27	1190.71	0.02		WRST NP/P	Strickland	Hannah

Table E.1. *Continued.* Aerial survey data for Dall's sheep, 1949-2002, in Wrangell-St. Elias National Park and Preserve, Alaska.

a) Count area is the same as survey area
b) Surveys were flown between 14 June and 8 August with the exception of 2 surveys in 1967 which were flown 30 November and 1 December
c) These sheep were not categorized by observers.
d) Area here is *surface area* which was estimated using 60m digital elevation models
e) Density is estimated as sheep/ km^2 using surface area estimates
f) Maps refer to whether or not maps existed of the distribution of observed sheep groups within the survey unit. These maps were on file at both the park and Alaska Department of Fish and Game Glennallen and Tok offices.