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Digital Mapping Techniques to Determine Dall's Sheep Winter Habitat in the Yukon Territory

BY

Lauren K. Crooks

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Digital Mapping Techniques to Determine Dall's Sheep Winter Habitat in the Yukon Territory submitted by Lauren K. Crooks in partial fulfilment of the requirements for the degree of Master of Science.

J. Ronald Eyton
(Supervisor)

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Date: Oct. 7/88

ABSTRACT

The four major parameters defining Dall's sheep (Ovis dalli dalli) winter habitat are: (1) moderate to steep slopes, (2) south-facing slopes, (3) snow-free vegetated areas, and (4) proximity to escape terrain. This study compared known sheep wintering areas to digital terrain data and winter Landsat data to determine the limits of the first three parameters. Proximity to escape terrain was not investigated. Slope azimuth and slope magnitude terrain data sets were developed and used to determine the limits of the first two parameters. Snow-free areas were identified using Landsat Thematic Mapper band 1 (blue) data registered to a regular digital elevation model. A map overlay and intersection technique was used to map combinations of these parameters. The results were as follows: (1) slope magnitude (3° - 37°) was not a limiting factor in determining Dall's sheep winter habitat, however, the slope magnitude range eliminated some areas from consideration; (2) slope azimuth (110° - 260°) was the dominant controlling factor in determining Dall's sheep winter habitat; (3) snow-free areas were not a significant factor for defining Dall's sheep winter habitat. Snow depth may be a factor, but temporal Landsat data is required to define this parameter.

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I. INTRODUCTION

The identification of important wildlife habitats in the Yukon Territory has been limited by the vast areal extent of the land, the inaccessibility, and the associated costs of conducting field work in remote locations. Professional wildlife management has a history of less than twenty years in the Yukon Territory (Hoefs and Barichello, 1985). Demands on the land in terms of land use development, utilization of renewable and non-renewable resources, and native land claims are increasing. Land planners and wildlife managers urgently need quality base-level data at various scales to incorporate into the decision making process.

Present methods of information gathering on wildlife habitats are time consuming and costly (Holroyd, 1980; Jacobsen, 1980; Stelfox, 1980), and the existing data are unorganized and not easily retrieved. More efficient methods are required for effective management. The integration of digital satellite data with digital terrain data for habitat mapping would be an appropriate methodology for the Yukon Territory. Digital databases acquired with this new technology are easily updated and permit automated data analysis. Information extraction is consistent, accurate, and cost-effective. Overall, there is a smaller primary data acquisition cost, the information is relatively easy to acquire, and data are available for large inaccessible areas for any season of the year.

This thesis demonstrates how digital mapping techniques can be applied to the spatial analysis of Dall's sheep (<u>Ovis dalli</u>

dalli) winter habitat, in the Yukon Territory. The overall objective of the research was to investigate the integration of digital terrain data with digital satellite data as a tool for habitat management. Specific objectives involved the development and analysis of digital databases for the quantitative evaluation and modeling of Dall's sheep winter habitat, and included the following:

1. to develop terrain data sets describing the distributions of slope magnitude and slope azimuth;

2. to use the terrain data sets to obtain the quantitative parameters defining Dall's sheep winter habitat;

3. to determine snow-free areas from digital satellite imagery;

4. to identify potential sheep winter habitat areas using the process of map overlay and intersection of the terrain distributions (slope magnitude and slope azimuth) and the snow-free distribution.

II. WILDLIFE HABITAT

Background

Habitat maps are used to delineate areas which provide all of the requirements necessary for the survival and prosperity of a species. Conventional mapping and analysis of habitat has been comprised mainly of field work, interviewing of knowledgeable people, low-altitude aerial surveys, interpretation of aerial photographs, and manual data analysis (Holroyd, 1980; Jacobsen, 1980; Stelfox, 1980). These techniques are labor-intensive and expensive.

Recently, satellite imagery has been recognized as an economical and laborsaving alternative to conventional data gathering methods for habitat mapping and analysis. Geometrically-corrected digital satellite imagery provides a cost-effective means for incorporating resource data into the planning and management processes (Henderson, 1984; Ihemadu, 1985). Digital satellite data has been used to evaluate the vegetation component of habitats for mammals, such as moose in Alaska (Laperriere et al., 1980) and Manitoba (Dixon et al., 1984), caribou in the Northwest Territories (Thompson et al., 1980), and grizzly bear in Montana and Alaska (Craighead et al., 1985). Digital terrain data has mainly been used as a tool in habitat mapping to improve classification accuracy of digital satellite data (e.g. Hutchinson, 1982). For example, Craighead et al. (1982) used digital terrain data to separate Landsat-derived vegetation zones by elevation for the mapping of grizzly bear habitat in Montana.

To achieve truly representative habitat maps for alpine mammals, relevant ancillary terrain data (elevation, slope magnitude, and slope azimuth) must be incorporated into the habitat classification and mapping process. A study conducted by Stefanovic and Wiersema (1985) in the European Alps, demonstrated the utility of digital terrain data for modeling insolation as the principal parameter in alpine ibex habitat. Terrain parameters were more important to this species of wild goat than vegetation types (Stefanovic and Wiersema, 1985). Similarly, Dall's sheep distributions are also considerably influenced by terrain parameters (Nichols, 1978). After an exhaustive search of the literature, only one example could be found of the digital mapping of terrain and land-cover components of habitat using integrated satellite image data and terrain data. Bonner et al. (1982) used elevation, slope magnitude, and Landsat-derived vegetation data sets to produce a map of potential bighorn sheep habitat.

Most of the published literature concerning the incorporation of digital satellite data into habitat mapping has utilized summer imagery to provide vegetation information. Comparatively little work has been undertaken using digital winter imagery for snow-cover mapping. Snow cover is one of the most significant factors governing the survival of northern ungulates (Formozov, 1946; Pruitt, 1959; Skogland, 1978; Telfer and Kelsall, 1979), and thus the identification of snow-free areas is imperative information needed for proper management practices (Jaques, 1982). Wiersema (1983), in a study focused on ibex habitat, employed three techniques for detection of snow-free areas in a Landsat Multispectral Scanner System (MSS) scene acquired over the French and Italian Alps. These techniques included: (1) an unsupervised approach to digital classification to locate snow-free migration routes; (2) a visual interpretation of Landsat band 5 (red) brightness maps to determine snow-cover boundaries and transient snow lines; and (3) a visual interpretation of false colour composites to locate snow-free vegetated areas. Jaques (1982) investigated four techniques for identifying non-forested snow-free areas as potential critical winter habitat for native ungulates in the Rocky Mountains of Alberta using Landsat MSS data. The four image analysis techniques were: (1) the visual interpretation of color infrared composite images; (2) single theme density slicing for each MSS band; (3) an unsupervised approach to multispectral cluster analysis; and (4) a multitemporal classification approach where a summer scene was used to classify non-forested areas and a winter scene was used to identify snow-free areas. Jaques (1982) concluded that the fourth approach produced the most accurate maps of critical winter range.

Dall's Sheep Winter Habitat

Dall's sheep along with Stone's sheep (Ovis dalli stonei) are subspecies of the thinhorn species (Ovis dalli) of North American sheep (Nichols, 1978). Dall's sheep are found in Alaska, the Yukon Territory, the Northwest Territories, and the extreme northwestern part of British Columbia (Nichols, 1978). The Yukon Territory contains the "largest wild sheep population of any jurisdiction in Canada" (Hoefs and Barichello, 1985:16). Hoefs and Barichello (1985) estimated the Dall's sheep population in the Yukon Territory at 19,000.

Dall's sheep habitat lies almost entirely above tree line and consists of steep, dry, south-facing grassland slopes interspersed with broken cliffs and talus slopes (Geist, 1971; Hoefs, 1974; Nichols, 1978; Hoefs and Cowan, 1979). There are four major parameters that define Dall's sheep winter habitat (Hoefs, pers.comm., 1987; Barichello, pers. comm., 1987): (1) moderate to steep slopes, (2) south-facing slopes, (3) snow-free vegetated areas, and (4) proximity to escape terrain (Geist, 1971; Hoefs, 1974; Nichols, 1978; Hoefs and Cowan, 1979). These parameters have all been previously expressed in qualitative terms. This thesis addressed the first three parameters defining winter habitat using digital terrain data and satellite data.

The vegetation types associated with Dall's sheep winter habitat were not examined in this study. The major vegetation types consumed by Dall's sheep are associated with dry, exposed, alpine grasslands (Hoefs and Cowan, 1979). These grassland associations are found mainly on south-facing slopes, and therefore the identification of the vegetation component is a consequence of the identification of south-facing slopes. The fourth parameter, proximity to escape terrain, was also excluded from this project. Digitally defining and quantifying escape terrain is a complex process and warrants a separate study. No such study has yet been attempted.

Winter is one of the most critical times in the life cycle of Dall's sheep. From late winter until spring very little food is available and the sheep depend heavily on stored body fat for nutritional needs. During this period the population is concentrated in areas where snow-free feeding sites are found in close proximity to escape terrain (Nichols, 1978; Hoefs and Cowan, 1979). Winter range is limited by snow conditions to a very small portion of the overall range (Nichols, 1978). In early winter the snow is soft and sheep can paw through to the vegetation (Geist, 1971; Nichols, 1978; Hoefs and Cowan, 1979). In late winter, however, the snow is often wind packed and impenetrable. Consequently, in late winter sheep depend on the steep, south-facing, and/or wind-scoured ridges that remain snow free (Nichols, 1978; Hoefs and Cowan, 1979), making this the critical time to detect snow-free areas.

Watson/Wheaton Study Area

The study area is situated within the planning region designated by the Yukon Department of Renewable Resources as the Watson/Wheaton Pilot Project. A helicopter survey conducted within this region during March, 1987 served as the basis for this research. The study area is located approximately 25 km south of the city of Whitehorse, and is bounded in the south by the British Columbia/Yukon Territory border. Located between latitudes 60° 00' and 60° 30' north and between longitudes 134° 44' and 135° 48' west, this 3267 km^2 area encompasses approximately one quarter of the National Topographic Series (NTS) 1:250,000 map 105D. Dimensions of the study area are 55 km in the north-south direction by 59.4 km in the east-west direction.

Situated within the Coast Mountains Ecoregion (Oswald and Senyk, 1977), the terrain is very rugged, ranging in elevation from 650 m asl at Lake Bennett to over 2500 m asl in the southern part of the mountains with several ice-covered peaks above 2400 m asl. The Coast Mountains Ecoregion falls within the discontinuous scattered permafrost subzone, much of the areas lies above treeline (Oswald and Senyk, 1977), and the climate is subarctic continental (Wahl et al., 1987). A low sun angle and long winter nights are typical for this latitude with less than six hours of sunshine received on December 21 at a maximum solar elevation of 6° (Wahl et al., 1987).

In Carcross, the nearest meteorological station to the study area, the average annual snowfall is 101.3 cm, with most snow falling between November and March (Table 1). January is the coldest month with temperatures averaging -19.8 °C (range -15.1 °C to -24.8 °C). The mean March temperature is -8.3 °C (-1.8 °C to -14.8 °C) with a mean snowfall of 10.2 cm (Atmospheric Environment Service, 1982a). Average snow-depth data is not available for Carcross.

Table 2 contains a summary of the weather data for March 1987, the period pertaining to this study. The mean temperature during March, 1987 was -12.0 °C (range 6.0 °C to -35.5 °C) with 7 cm of snow falling for a total snow depth of 15 cm (Atmospheric Environment Service, 1987). According to Wahl et al. (1987), snow depths reach their maximum by early to mid-April at elevations greater than 1000 m in the southern part of the Yukon Territory. The closest meteorological station with wind data is Whitehorse. In March, the prevailing wind direction varies from southeast to south, with average wind speeds of 19.7 km/h from the southeast and 17.2 km/h from the south (Table 3). Dominant wind directions over the interior Yukon Territory coincide mainly with the valley orientations (Wahl et al., 1987).

TABLE 1

Average Climate Data for Carcross, Yukon Territory (1951-1980)

	Month												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Daily maximum temperature (°C)	-15.1	-7.7	-1.8	5.6	11.5	16.7	18.9	17.9	12.3	5.1	-3.9	-11.2	4.0
Daily minimum temperature (°C)	-24.8	-18.7	-14.8	-5.9	-0.5	4.6	6.4	4.9	1.4	-3.2	-12.0	-19.8	-6.9
Daily mean temperature (°C)	-19.8	-13.2	-8.3	-0.2	5.5	10.7	12.7	11.4	6.9	0.9	-7.9	-15.5	-1.4
Rainfall (mm)	0.2	1.0	0.0	1.8	11.5	14.9	19.2	21.2	19.8	12.8	4.7	11.6	118.7
Snowfall (cm)	24.2	17.8	10.2	4.3	0.3	0.4	0.0	0.0	2.4	4.8	18.2	18.7	101.3
Total * precipitation (mm)	19.4	16.5	12.6	6.5	11.8	15.0	19.2	21.2	21.8	20.4	22.9	24.1	211.4
Days with precipitation	6	6	4	2	4	6	7	7	7	7	8	8	72

* Rainfall + water equivalent of snowfall.

Source: Atmospheric Environment Service (1982a).

TABLE 2
March, 1987 Weather Summary for Carcross, Yukon Territory

Snowfall (cm)	7.0
Snowdepth (cm)	15.0
Maximum temperature (°C)	6.0
Minimum temperature (°C)	-35.5
Mean temperature (°C)	-12.0

Source: Atmospheric Environment Service (1987).

TABLE 3
Average March Wind Data for Whitehorse, Yukon Territory (1953-1978)

Wind direction	% frequency	Average wind speed (km/h)
NNE	0.6	12.3
NE	0.3	6.3
ENE	0.1	9.7
E	0.5	10.6
ESE	1.6	18.0
SE	14.9	19.8
SSE	17.8	20.2
S	14.7	16.8
SSW	2.3	16.1
SW	2.4	11.9
WSW	1.6	10.9
W	3.2	8.7
WNW	2.3	9.9
NW	11.4	13.6
NNW	6.7	14.9
N	7.3	13.5
Calm	12.3	
All directions		14.3

Source: Atmospheric Environment Service (1982b).

III. DATABASE DEVELOPMENT

Digital Terrain Data

Digital topographic information in the form of a generated grid of elevations or a digital elevation model (DEM) was required for this research. A portion of a 1:250,000 National Topographic Series (NTS) map was digitized using the Interactive Graphic Design System (IGDS) software developed by the Intergraph Corporation, running on a VAX-11/730 minicomputer. Each 500 foot contour was digitized using point mode sampling. Large flat areas were supplemented by digitizing additional contours and points from 1:50,000 NTS maps of the area.

The digitized lines, comprised of X and Y coordinates and their associated Z (elevation) values, resulted in a total of 27383 sets of triplets. To create a regular grid of elevation values, these triplets were surfaced using a multiquadric equation algorithm based on an analytical interpolation approach developed by Hardy (1971) and implemented in roving form by Eyton and Hemenway (1987). The number of calculations performed by this surfacing routine is quite extensive; approximately 23 hours of CPU time on a VAX-11/730 were required. The resulting DEM contained 550 rows and 594 columns with each grid cell covering a 100 m by 100 m area on the ground. Multiquadric surfacing was used because the equations were designed for topographic expression where the fitted surface must pass through all of the observation points exactly (Hardy, 1971). The DEM was then smoothed once using a low-pass spatial filter to remove local irregularities. Figure 1 shows a perspective plot of the smoothed DEM. Latitude, longitude, and north are indicated on this figure. Where appropriate, the rest of the figures are oriented with north at the top.

Derivative products obtained from the DEM supplied the necessary information regarding landscape geometry. Slope magnitude and slope azimuth data sets were derived from the smoothed DEM using an algorithm developed by Eyton (1987a). This algorithm employs the method of finite differences applied to a 3 x 3 neighborhood to obtain the slope magnitude and slope azimuth components of the first spatial derivative. The derived data sets were identical in size and locational reference to the original grid of elevation values. These data sets were used to quantify the first two parameters defining Dall's sheep winter habitat: slope magnitude and slope azimuth. A hillshaded map, based on a Lambertian reflectance model (Eyton, 1988), was created from the slope and azimuth data sets and used as a map base for most of the illustrations presented in this study.

Habitat Polygons

Dall's sheep winter habitat areas (polygons) were delineated on a 1:100,000 topographic map during a helicopter survey conducted by Yukon Territorial Government biologists on March 19 and 25, 1987. The helicopter survey covered all known winter ranges of Dall's sheep within the study area (Hoefs, pers. comm.,

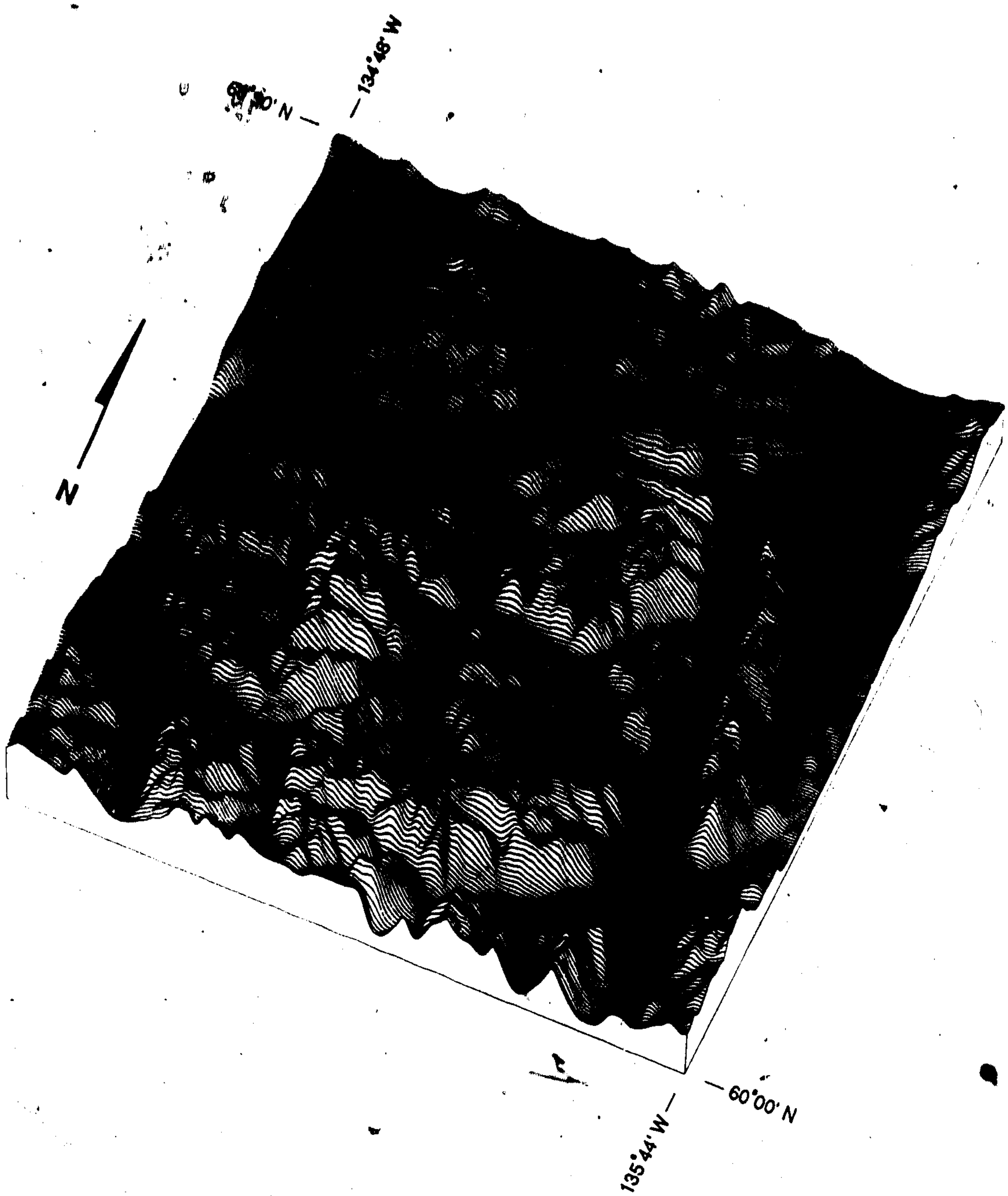

FIGURE 1. Perspective plot of the smoothed DEM (with 5X vertical exaggeration) of the Watson/Wheaton study area, Yukon Territory. The viewing perspective is from the SSE (azimuth=157.5°) at an observer altitude of 60°.

1987). This survey was described by Hoefs (pers. comm., 1987) as a complete but low intensity survey; the entire area was flown, but with only a single pass. In this survey, the locations of the polygons were based on sightings of sheep or concentrations of tracks. The field expertise of the biologist was of paramount importance in determining the polygon boundaries. Areas which Yukon biologists indicated were marginal winter habitat were excluded from this study.

Forty-eight polygons from the 1:100,000 map were digitized, and a binary (sheep/no sheep) digital mask was produced using a vector-to-raster procedure (Eyton, 1987b). The digital mask registered with the digital terrain data sets. Figure 2 shows the digital mask overlaid on the hillshaded map to indicate the location of the Dall's sheep winter habitat polygons. The digital mask was used to extract information for the winter habitat polygons from the digital elevation model and from the slope magnitude and slope azimuth derivative models.

Landsat Data

A Landsat Thematic Mapper (TM) image (#51111-193421) was obtained for March 17, 1987. The satellite pass occurred two days prior to the winter aerial survey from which the sheep winter habitat polygons were delineated. The Landsat digital data was used to identify snow-free areas within the study area. The image data was initially processed using the CAL 3 linear radiometric calibration process at the Prince Albert Satellite Station. This

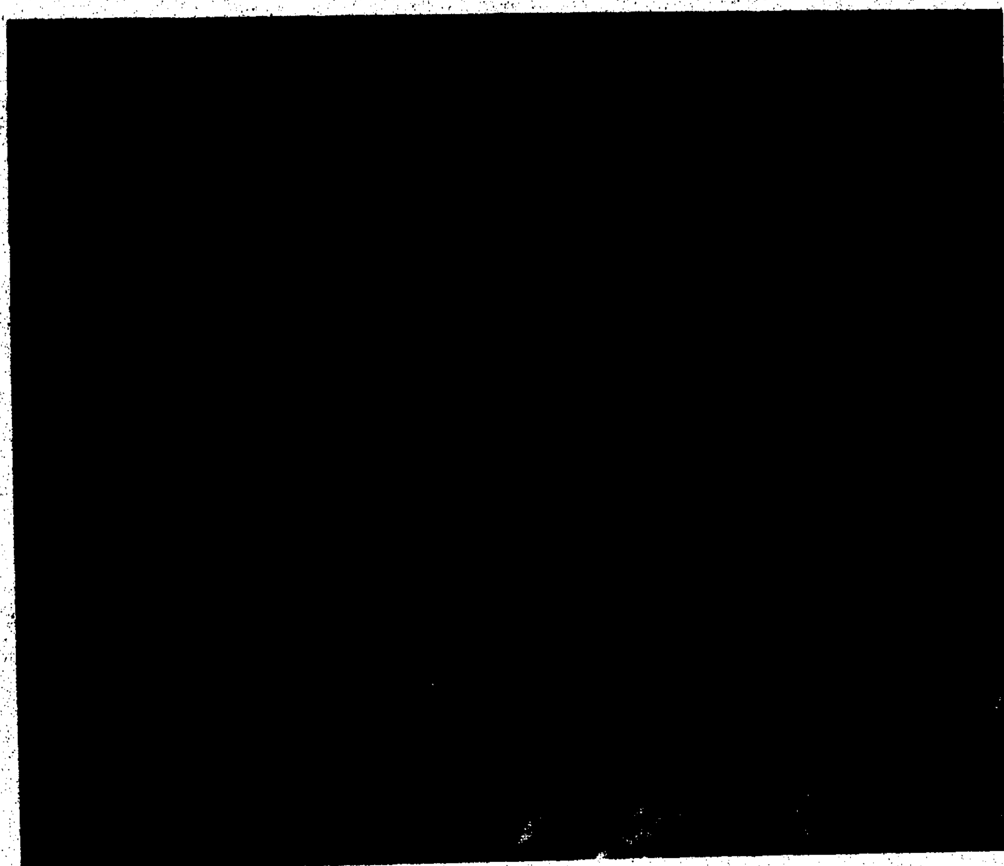

FIGURE 2. Digital mask overlaid in black on a hillshaded map of the Watson/Wheaton study area, Yukon Territory. Illumination is from the northwest (azimuth=315°) at a solar altitude of 45°.

procedure retains the majority of the dynamic range of brightness values, providing improved coverage of bright and dark extremes (Ahern and Murphy, 1978; Ahern, 1979; Ahern et al., 1987). To achieve registration with the other digital data sets, the image quadrant was subset and geometrically corrected to a Universal Transverse Mercator projection. The pixels were resampled to 100 m grid cells using nearest-neighbor interpolation; overall accuracy of the registration was approximately 33 meters (the difference between the estimated and the actual row and column coordinates of the 18 ground control points in the original image). The nearest-neighbor method "is the preferred technique if the new image is to be classified since it then consists of the original pixel brightnesses, simply rearranged in position to give a correct image geometry" (Richards, 1986:53). These transformations were conducted at the Alberta Remote Sensing Center using the DIPIX LCT-11 (ARIES 11) digital image analysis system.

The Landsat TM quadrant encompassed the majority of the study area, excluding the extreme northeast corner. Data dropouts in lines or groups of pixels were present in all bands due to equipment failure during transmission from satellite to receiving station. One particularly large dropout, 16 entire lines, was flagged to indicate missing data.

IV. ANALYSIS AND MAPPING OF DALL'S SHEEP WINTER HABITAT

Two objectives of this research were to quantitatively define (1) the terrain limits, and (2) the snow-free areas for Dall's sheep winter habitat. Once these quantitative parameters were established, a map overlay and intersection process was used to achieve the third and final objective; (3) the identification of potential sheep winter habitat areas in the study area. A brief overview of the procedure is given below to clarify the detailed discussion which follows.

The digital mask, indicating the location of Dall's sheep from the March, 1987 aerial survey, was used to extract the slope magnitude and slope azimuth values characterizing sheep habitat from the terrain data sets. These distributions were first plotted as histograms and the limits defining the range of each distribution was determined by removing outliers. These outliers were likely due to measurement error, however, even if they were not, removal was justified because there is a low probability of their occurrence. The limits defining the maximum and minimum of this range are called clipping levels or threshold values. This project involved the overlay and intersection of multiple data layers, therefore, a liberal approach for determining clipping levels was adopted. The slope magnitude and slope azimuth ranges, and snow-free sites characterizing sheep winter habitat were then used to identify potential winter areas within the study area for sheep which were not identified in the March, 1987 aerial survey.

Slope Magnitude

The distribution of slope magnitude values for each grid cell of the study area (Figure 3a) shows an abundance of gentle slopes and comparatively few steep slopes. Within the study area there is a marked concentration of slopes with less than 10° magnitude and a very low frequency of slopes above 45°. The steepest slopes within the region are approximately 56° magnitude. A gray scale map of the slope magnitude distribution for the entire area is shown in Figure 4.

The slope magnitude distribution characterizing sheep winter habitat (Figure 3b) differs markedly from the distribution of slope magnitude for the entire study area (Figure 3a). The histogram in Figure 3b shows a positively skewed distribution, a pronounced mode with a frequency of 4.4% occurring at 23°, and a large variation about the mode. Removal of data outliers was accomplished by excluding slope values having a frequency of occurrence of less than 1% resulting in approximately 2% and 4% of the slope magnitude observations being excluded from the left and right ends of the distribution, respectively. This 1% frequency cutoff produced a slope magnitude range of 3° to 37°. This range was characteristic of approximately 94% of the Dall's sheep winter habitat area (Table 4). Grid cells with values between 3° and 37° were extracted from the slope magnitude data set and displayed as a black tone. The boundaries (in white) of the sheep winter habitat polygons were overlaid on the single-class map shown in Figure 5. This map shows the areal extent of

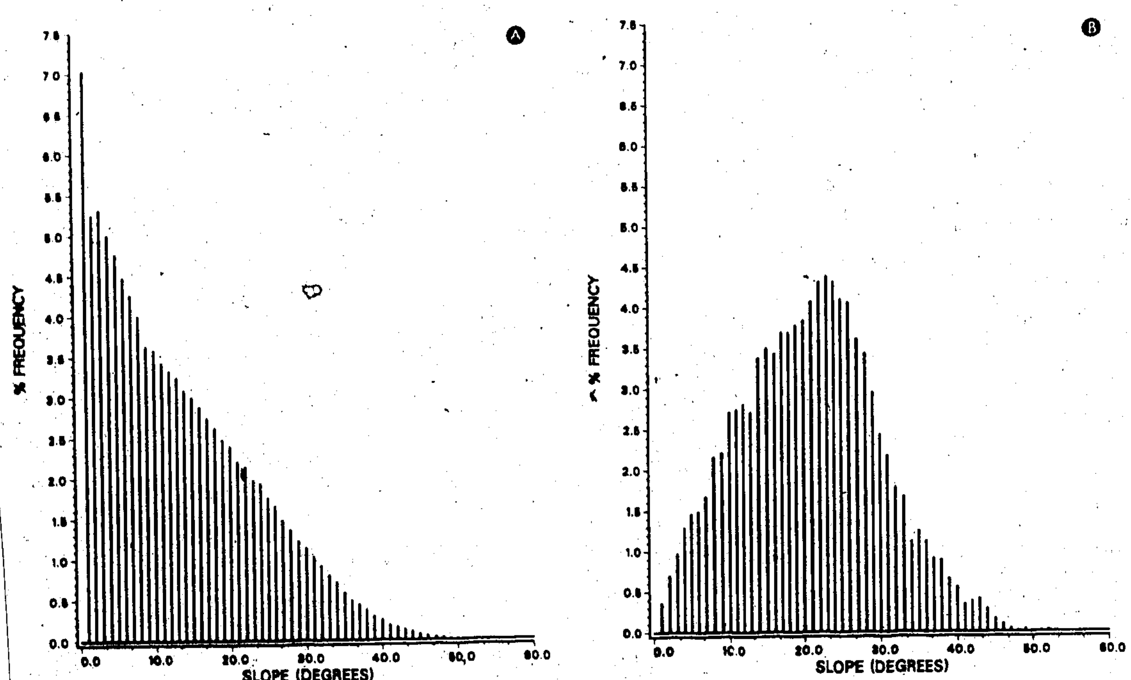

FIGURE 3. Frequency distributions of slope magnitude for (a) the entire study area, and (b) the sheep winter habitat polygons.

FIGURE 4. Gray scale map of the slope magnitude distribution for the study area. Light tones indicate steep slopes and dark tones indicate gentle slopes.

TABLE 4
Areal Extent of Habitat Parameters

Habitat parameter(s)	%of polygon area accounted for by habitat parameter	% of study area encompassed by habitat parameter
Slope magnitude*	94.1	80.7
Slope azimuth**	70.4	37.6
Snow-free, non-forested areas	12.1	9.6
Slope magnitude*/ slope azimuth**	68.7	30.6
Slope magnitude*/slope azimuth**/snow-free, non-forested areas	4.9	1.5

* range: 3° - 37°
** range: 110° - 260°

FIGURE 5. Single-class map of the study area showing the distribution of slope magnitude characterizing Dall's sheep winter habitat in black. The boundaries of the habitat polygons are overlaid in white.

the slope magnitude range characterizing sheep winter habitat. The range of acceptable slope magnitude values is quite large, encompassing 81% of the study area (Table 4), thus slope magnitude was not an important parameter for defining winter habitat within this area. The slope magnitude range, however, did eliminate some areas from consideration as potential sheep winter habitat in the last part of the analysis.

Slope Azimuth

The percent frequency of grid cells (covering the entire study area) for each degree of slope azimuth was plotted as a circular histogram (Figure 6a). The distribution indicates that the topography is not predominantly oriented in a specific direction, however, there is a slight tendency for slopes to be northwest or southeast oriented. A gray scale map of slope azimuth for the entire area is shown in Figure 7. This gray scale map illustrates the global variation of slope azimuth within the study area and corroborates what is shown in the histogram; no dominant orientation is apparent.

The frequency of slope azimuth grid cells characterizing Dall's sheep winter habitat were plotted as a circular histogram in Figure 6b. In contrast to Figure 6a, this graph exhibits a very pronounced trend of south-facing slopes, especially southwest-facing slopes. Inspection of the graph indicates two primary modes occurring at 127.5° and 142.5° with approximately 3.5% frequency of occurrence for each mode. Four secondary modes

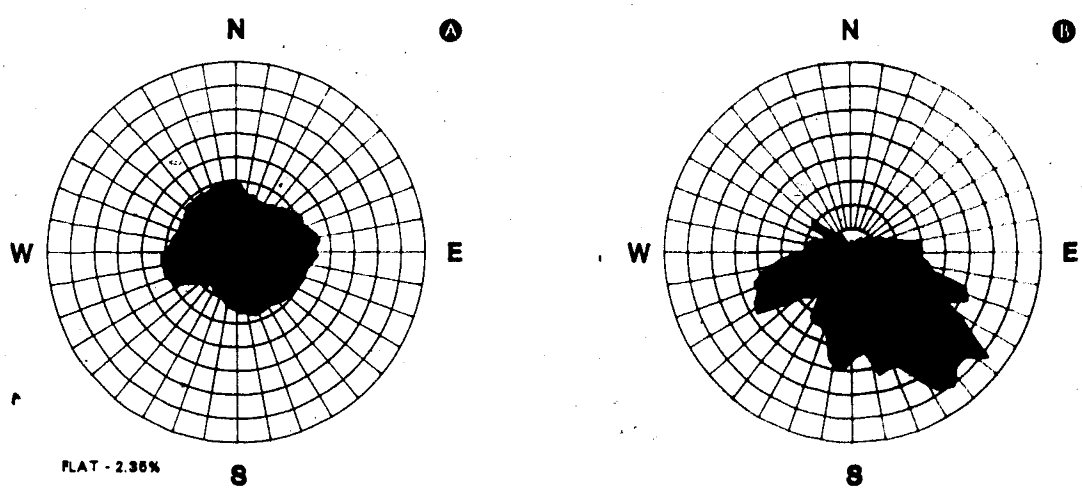

FIGURE 6. Frequency distributions of slope azimuth for (a) the entire study area, and (b) the sheep winter habitat polygons. The radial lines represent 10° intervals of slope azimuth, the radial rings represent 0.5% frequency intervals, and the outer ring indicates 4% frequency.

FIGURE 7. Gray scale map of the slope azimuth distribution for the study area. North-facing slopes are black, west-facing slopes are dark gray, east-facing slopes are medium gray, south-facing slopes are light gray, and flat areas are white.

are also evident (112.5°, 167.5°, 187.5°, and 237.5°) with approximately 2.5% frequency of occurrence for each mode. On the basis of the biologists' helicopter survey, it appears that sheep winter habitat is characterized by southwest- to southeast-facing slopes. Clipping levels of 110° and 260° (determined by simple inspection of the graph) were used to map the slope azimuth range describing winter habitat. Approximately 70% of the Dall's sheep winter habitat area was accounted for by the slope azimuth range (Table 4). Those grid cells contained within the clipped range were displayed as a single-class map overlaid on the hillshaded map with the boundaries of the sheep habitat polygons added in white (Figure 8). Slope azimuth may be a stronger controlling factor than slope magnitude for the winter distribution of sheep because the slope azimuth distribution is better defined from the observational data than the slope magnitude distribution. The clipped slope azimuth range encompassed 38% of the study area (Table 4).

Snow-free Sites

Snow-free sites were identified by level slicing (thresholding) Landsat TM band 1 (blue) data. The blue band was used because the shorter wavelengths are scattered more than the other wavelengths of visible radiation that interact with gas molecules in the earth's atmosphere (Lillesand and Kiefer, 1979). The scattered light present in the scene illuminated those areas in shadow enabling the detection of snow-free surfaces. Snow/no

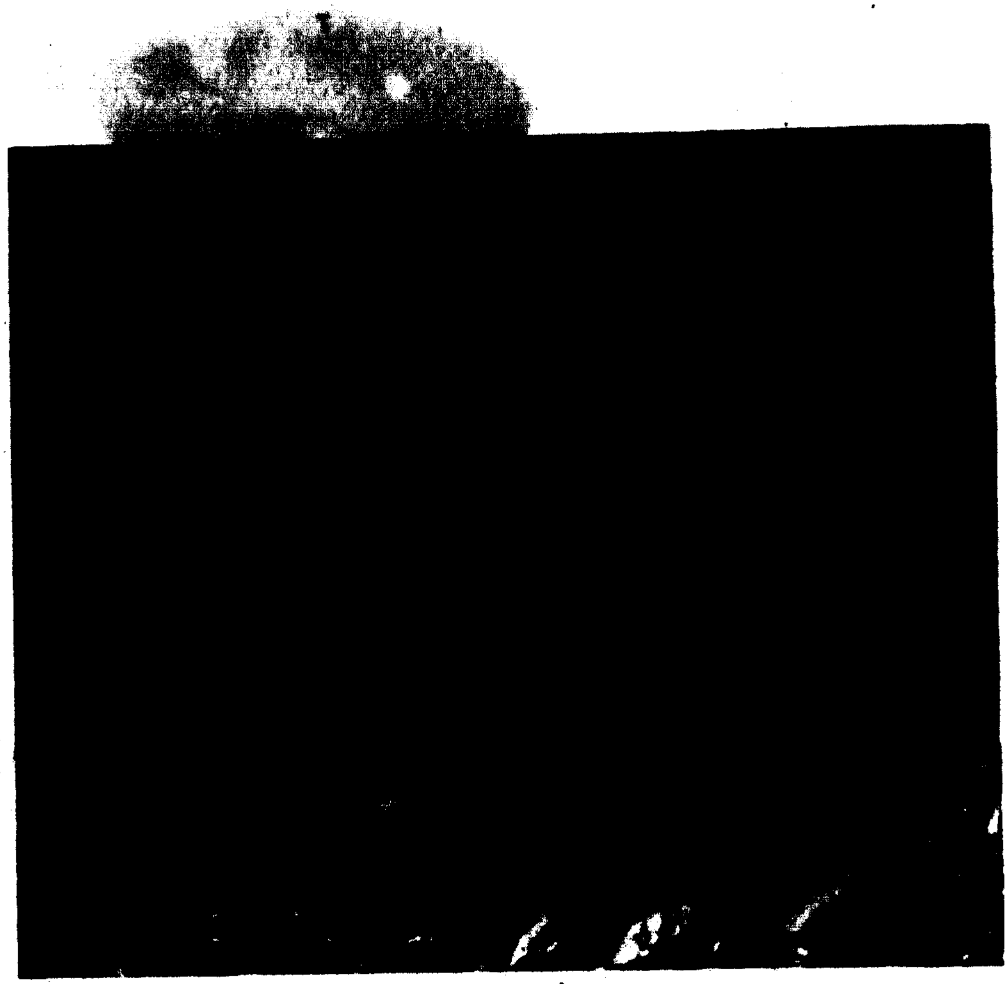

FIGURE 8. Single-class map of slope azimuth range defining Dall's sheep winter habitat overlaid in black on the hillshaded map of the study area. The boundaries of the habitat polygons are added in white.

snow pixels were identified and located on a line-printer brightness map of TM band 1 data. Color photographs acquired during the March (1987) helicopter survey, single band images of each of the 7 Landsat bands, and normal color and color infrared composites were used as aids in this process. The threshold of snow was determined by examining the brightness values of individual pixels from representative samples of snow/no snow interfaces within the scene. Brightness values below 150 indicated snow-free areas and brightness values above 150 indicated snow-covered areas.

Non-forested, snow-free areas were difficult to distinguish from forested areas by level slicing. The mislabeling of forested sites as non-forested, snow-free sites was reduced by eliminating forested sites from the snow-cover labelling. The elimination of these sites was justified because Dall's sheep winter habitat lies above tree line (Nichols, 1979; Hoefs and Cowan, 1979). The upper limit of tree line occurs at approximately 1050 m within the study area (Oswald and Senyk, 1977). Using the DEM and the Landsat band 1 data, image grid cells with brightness values less than 150 and elevation grid cells with values greater than 1050 m were classified as snow free and non-forested. The locations of snow-free, non-forested pixels are shown in black on the hillshaded map (Figure 9). The boundaries of the sheep winter habitat polygons were overlaid in white on the single-class map to show the location of the polygons relative to the snow-free, non-forested areas. Only 9.6% of the area covered by the Landsat image was snow free on March 17, 1987 (Table 4). Much of this

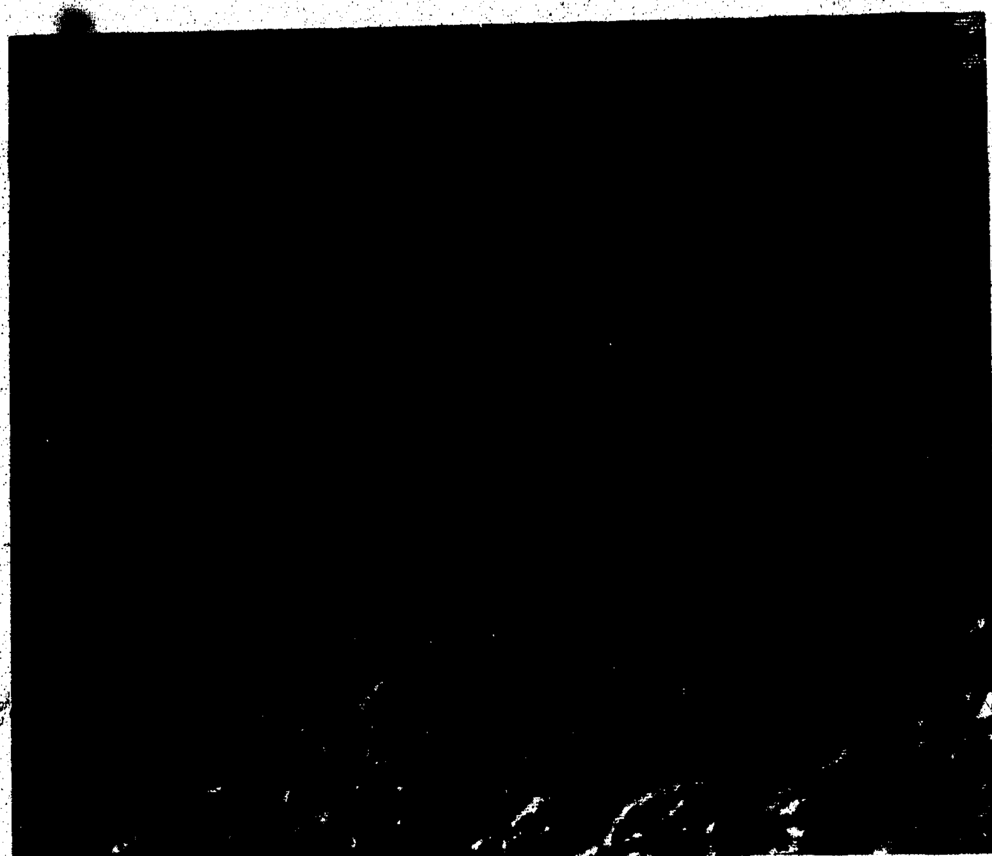

FIGURE 9. Single-class map of snow-free, non-forested sites shown in black overlaid on the hillshaded map of the study area. The boundaries of the habitat polygons are overlaid in white on the single class map.

area, however, occurs within shadow and may not be snow free. The elimination of shadowed areas will be discussed later.

The digital mask was used to quantitatively define the characteristics of Dall's sheep winter habitat in terms of the areal extent of the snow cover. Approximately 12% of the area covered by the habitat polygons was snow free (Table 4). The northernmost polygon was excluded from the analysis as it fell outside of the area covered by the Landsat image. When each polygon was considered individually, only 16 of the 47 polygons exceeded a frequency of 10% snow free (Table 5); most of the polygons contained very few or no snow-free pixels. The snow-free parameter was not a significant factor in defining Dall's sheep winter habitat for this area at this time of year.

Snow depth cannot be ascertained using a single Landsat scene. Inferences concerning the depth of snow can be made as follows: (1) the presence of snow-free pixels within polygons may be indicative of thinning snow within those polygons, (2) the presence of snow-free pixels adjacent to polygons may be indicative of thinning snow within nearby polygons, (3) the absence of snow-free pixels within polygons or adjacent to polygons may indicate snow depth was not a controlling factor at this time of year. As shown in Figure 9, the majority of polygons met the first condition indicating that a majority of the polygons may contain thinning snow.

TABLE 5
Frequency of Snow-free Pixels for Habitat Polygons

Habitat polygon	Snow-free pixels	Total pixels	% frequency snow-free
1	19	66	28.79
2	9	34	26.47
3	19	106	17.92
4	1	47	2.13
5	2	40	5.00
6	3	34	8.82
7	16	27	59.26
8	0	363	0.00
9	14	65	21.54
10	23	251	9.16
11	10	320	3.13
12	97	97	100.00
13	6	92	6.52
14	23	140	16.43
15	85	421	20.19
16	41	426	9.62
17	27	168	16.07
18	3	255	1.18
19	1	148	0.68
20	4	59	6.78
21	10	144	6.94
22	0	157	0.00
23	2	265	0.75
24	8	63	12.70
25	13	54	24.07
26	15	223	6.73
27	2	224	0.89
28	441	1286	34.29
29	56	95	58.95
30	23	73	31.51
31	3	64	4.69
32	5	70	7.14
33	24	273	8.79
34	2	346	0.58
35	20	278	7.19
36	56	654	8.56
37	8	614	1.30
38	11	190	5.79
39	0	59	0.00
40	3	71	4.23
41	7	79	8.86
42	31	305	10.16
43	39	153	25.49
44	1	305	0.33
45	0	106	0.00
46	4	289	1.38
47	0	226	0.00

Identification of Potential Sheep Winter Habitat Areas

The process of map overlay and intersection of the terrain distributions and the snow-free distribution was employed to produce two maps: (1) a slope magnitude and slope azimuth intersection map, and (2) a slope magnitude, slope azimuth, and snow-free intersection map. The intersections of the defined ranges of slope magnitude (3° - 37°) and slope azimuth (110° - 270°) characterizing sheep winter habitat were overlaid in black on the hillshaded map shown in Figure 10. The boundaries of the sheep habitat polygons in white were also included. This map differs very little from Figure 8 (the single-class map of slope azimuth) but differs markedly from Figure 5 (the single-class map of slope magnitude) indicating again that slope azimuth is a more significant controlling factor than slope magnitude. The combination of these 2 parameters encompassed 31% of the study area (Table 4). Sixty-six percent of the sheep winter habitat area was accounted for by the defined ranges of the combined slope azimuth/slope magnitude map. Those polygons which did not fall within the slope magnitude and slope azimuth ranges may be explained by other factors discussed later.

Map overlay and intersection of the slope azimuth and slope magnitude terrain distributions and the snow-free distribution was used to create the single-class map shown in Figure 11. The single-class map was overlaid in black on the hillshaded map along with the boundaries of the sheep habitat polygons. The

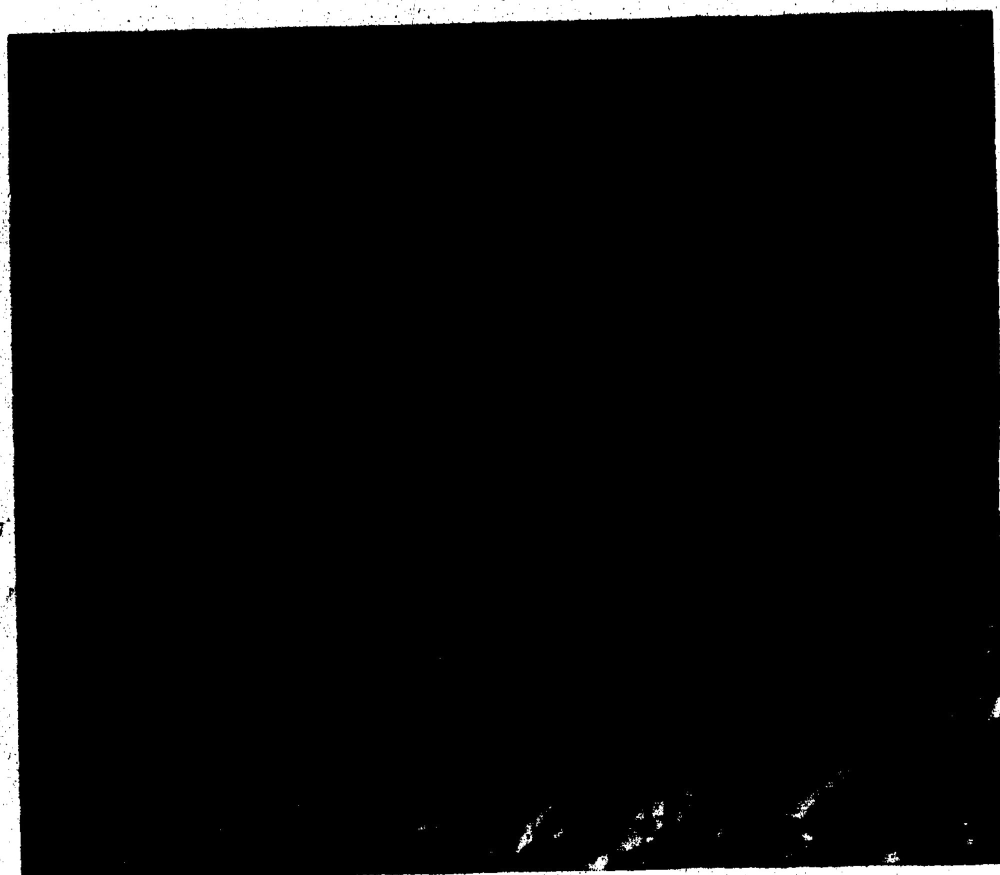

FIGURE 10. Single-class map of slope magnitude and slope azimuth ranges characterizing Dall's sheep winter habitat overlaid in black on the hillshaded map of the study area. The boundaries of the habitat polygons are overlaid in white.

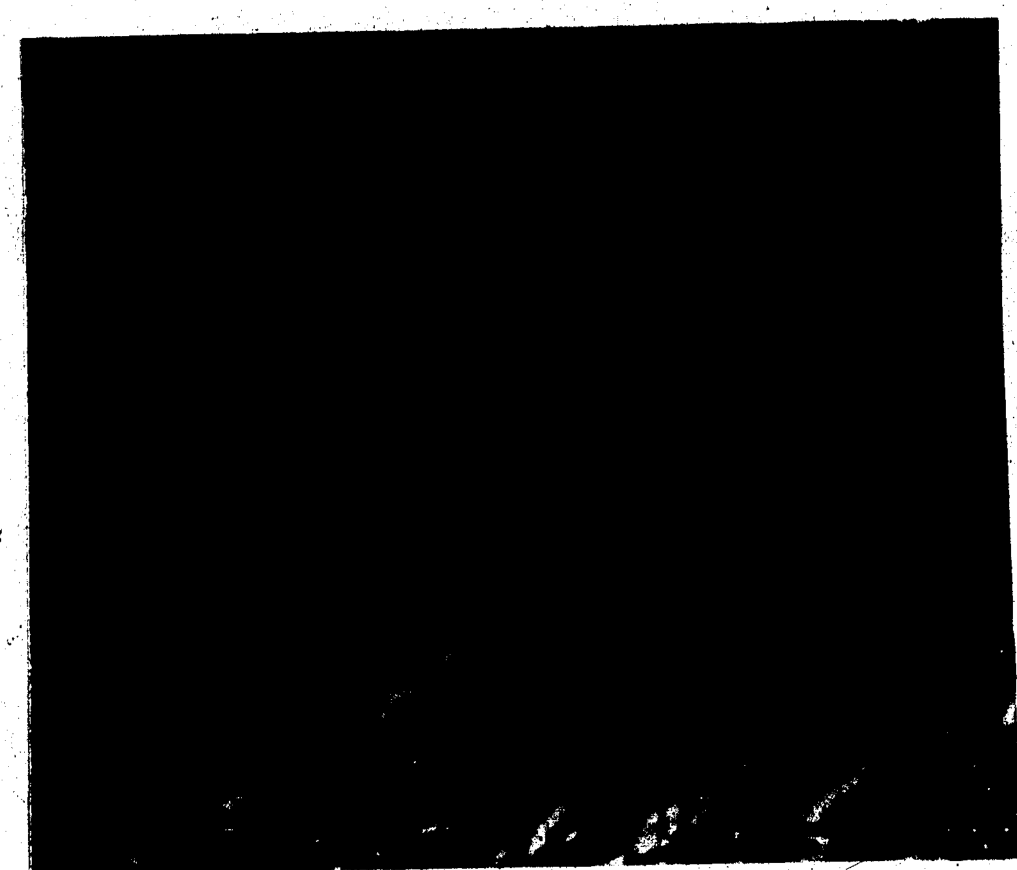

FIGURE 11. Single-class map of slope magnitude and slope azimuth ranges characterizing Dall's sheep winter habitat in conjunction with the snow-free, non-forested sites. The single class is shown in black on the hillshaded map of the study area and the habitat polygons are shown as white boundaries.

defined ranges of these parameters accounted for 5% of the sheep winter area (Table 4). Very few areas fell within the slope magnitude and slope azimuth range characterizing Dall's sheep winter habitat that were also snow free. This combination essentially removed shadowed areas (north facing) from the snow-free, non-forested binary map (Figure 9), to produce a map representing the actual snow-free areas (1.5% of the study area - refer to Table 4).

Snow depth was probably a greater controlling factor than absence or presence of snow in determining Dall's sheep winter habitat. Sheep can paw through snow to the vegetation if the snow is soft and shallow (Geist, 1971; Nichols, 1978; Hoefs and Cowan, 1979). The snow depth in March, 1987 was only 15 cm and the mean temperature (-12 °C) was well below freezing (Table 2). The snow was likely thin and relatively soft allowing the sheep to penetrate the snow cover to reach the underlying vegetation.

Landsat data may be useful for identifying probable areas of shallow snow if a temporal analysis strategy is adopted. Those areas that were snow free before or after the helicopter survey date were likely thinner than other areas. The snow was probably shallow around the snow-free areas, therefore snow-covered pixels adjacent to snow-free pixels likely contained thinning snow. Landsat data was not recorded for the study area immediately before the survey date and the image acquired immediately after the survey date was cloud covered, consequently this approach could not be tested. Without multitemporal imagery, it is not possible to distinguish between thin snow and deep snow using possible to distinguish between thin snow and deep snow using Landsat data.

Slope azimuth appears to be the dominant controlling factor describing Dall's sheep winter habitat in the study area. The importance of slope azimuth is due to the relationship of vegetation, insolation, and wind to slope azimuth and the influence of insolation and wind on snow cover. The vegetation types consumed by sheep are found mainly on south-facing slopes which receive greater than usual insolation. In addition, the resulting melting combined with sublimation reduce the snow cover on these slopes. The predominant wind direction for March varies from the southeast to the south (Atmospheric Environment Service, 1982b), thus slopes with a south to southeast orientation will become wind blown resulting in thinner snow cover and snow-free sites.

The overall objective of this research was to develop spatial analysis techniques that would be useful for mapping Dall's sheep winter habitat. Figure 10 shows the best estimate of areas (in black) that meet the established criteria for Dall's sheep winter habitat. These potential habitat areas are based on the defined ranges of slope magnitude (3° - 37°) and slope azimuth (110° - 260°). Although untested at this time, the mapping of potential sheep habitat areas may be useful (1) to predict areas for sheep relocation, (2) to provide information for input into land use decisions, (3) to implement protective measures for sheep habitat, (4) to assist habitat managers in planning flight routes for winter aerial surveys, and (5) to increase the understanding of Dall's sheep habitat.

V. SUMMARY

A method for habitat mapping and analysis using digital satellite data and digital terrain data has been presented. This method was used to quantitatively evaluate the three of four major parameters that define Dall's sheep winter habitat in a 3287 km area, located south of Whitehorse, Yukon Territory. The four major parameters are: (1) moderate to steep slopes, (2) south-facing slopes, (3) snow-free vegetated areas, and (4) proximity to escape terrain.

Slope azimuth and slope magnitude terrain data sets were developed and used to evaluate the first two parameters defining Dall's sheep winter habitat. The third parameter, snow-free areas, was identified using Landsat TM band 1 data registered to a regular grid of elevation values. The fourth parameter, proximity to escape terrain, was not investigated.

The process of map overlay and intersection was employed to identify potential sheep winter habitat areas. The results were as follows:

(1) Slope magnitude was not a limiting factor in determining Dall's sheep winter habitat (3° - 37°), however, the slope magnitude range eliminated some areas from consideration as potential habitats. The slope magnitude range encompassed 81% of the study area and accounted for 94% of the sheep winter habitat area.

(2) Slope azimuth was the dominant controlling factor in determining Dall's sheep <u>winter</u> habitat. This parameter accounted

for 70% of winter habitat polygons and encompassed 38% of the study area. Southwest- to southeast-facing slopes (110° - 260°) characterize sheep habitat. The dominance of slope azimuth is due to the relationship of vegetation, insolation, and wind to slope direction and the influence of insolation and wind on snow cover. The vegetation types consumed by sheep are found mainly on south-facing slopes. South-facing slopes receive intense insolation resulting in reduced snow cover due to sublimation and melting. Due to the predominant southern wind during March, south-facing slopes become wind blown resulting in shallow snow and snow-free sites.

(3) Snow-free areas were not a significant factor for defining Dall's sheep winter habitat. Snow-free areas accounted for 5% of the winter habitat area and encompassed 1.5% of the study area. Snow depth may be a factor, but multitemporal Landsat imagery is required to identify probable areas of shallow snow. This technique could not be tested because multitemporal imagery was not available for the Watson/Wheaton planning region during the winter of 1987.

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Digital Mapping Techniques to Determine Dall's Sheep Winter Habitat in the Yukon Territory

BY

Lauren K. Crooks

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Digital Mapping Techniques to Determine Dall's Sheep Winter Habitat in the Yukon Territory submitted by Lauren K. Crooks in partial fulfilment of the requirements for the degree of Master of Science.

J. Ronald Eyton
(Supervisor)

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Date: Oct. 7/88

ABSTRACT

The four major parameters defining Dall's sheep (Ovis dalli dalli) winter habitat are: (1) moderate to steep slopes, (2) south-facing slopes, (3) snow-free vegetated areas, and (4) proximity to escape terrain. This study compared known sheep wintering areas to digital terrain data and winter Landsat data to determine the limits of the first three parameters. Proximity to escape terrain was not investigated. Slope azimuth and slope magnitude terrain data sets were developed and used to determine the limits of the first two parameters. Snow-free areas were identified using Landsat Thematic Mapper band 1 (blue) data registered to a regular digital elevation model. A map overlay and intersection technique was used to map combinations of these parameters. The results were as follows: (1) slope magnitude (3° - 37°) was not a limiting factor in determining Dall's sheep winter habitat, however, the slope magnitude range eliminated some areas from consideration; (2) slope azimuth (110° - 260°) was the dominant controlling factor in determining Dall's sheep winter habitat; (3) snow-free areas were not a significant factor for defining Dall's sheep winter habitat. Snow depth may be a factor, but temporal Landsat data is required to define this parameter.

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I. INTRODUCTION

The identification of important wildlife habitats in the Yukon Territory has been limited by the vast areal extent of the land, the inaccessibility, and the associated costs of conducting field work in remote locations. Professional wildlife management has a history of less than twenty years in the Yukon Territory (Hoefs and Barichello, 1985). Demands on the land in terms of land use development, utilization of renewable and non-renewable resources, and native land claims are increasing. Land planners and wildlife managers urgently need quality base-level data at various scales to incorporate into the decision making process.

Present methods of information gathering on wildlife habitats are time consuming and costly (Holroyd, 1980; Jacobsen, 1980; Stelfox, 1980), and the existing data are unorganized and not easily retrieved. More efficient methods are required for effective management. The integration of digital satellite data with digital terrain data for habitat mapping would be an appropriate methodology for the Yukon Territory. Digital databases acquired with this new technology are easily updated and permit automated data analysis. Information extraction is consistent, accurate, and cost-effective. Overall, there is a smaller primary data acquisition cost, the information is relatively easy to acquire, and data are available for large inaccessible areas for any season of the year.

This thesis demonstrates how digital mapping techniques can be applied to the spatial analysis of Dall's sheep (<u>Ovis dalli</u>

dalli) winter habitat, in the Yukon Territory. The overall objective of the research was to investigate the integration of digital terrain data with digital satellite data as a tool for habitat management. Specific objectives involved the development and analysis of digital databases for the quantitative evaluation and modeling of Dall's sheep winter habitat, and included the following:

1. to develop terrain data sets describing the distributions of slope magnitude and slope azimuth;

2. to use the terrain data sets to obtain the quantitative parameters defining Dall's sheep winter habitat;

3. to determine snow-free areas from digital satellite imagery;

4. to identify potential sheep winter habitat areas using the process of map overlay and intersection of the terrain distributions (slope magnitude and slope azimuth) and the snow-free distribution.

II. WILDLIFE HABITAT

Background

Habitat maps are used to delineate areas which provide all of the requirements necessary for the survival and prosperity of a species. Conventional mapping and analysis of habitat has been comprised mainly of field work, interviewing of knowledgeable people, low-altitude aerial surveys, interpretation of aerial photographs, and manual data analysis (Holroyd, 1980; Jacobsen, 1980; Stelfox, 1980). These techniques are labor-intensive and expensive.

Recently, satellite imagery has been recognized as an economical and laborsaving alternative to conventional data gathering methods for habitat mapping and analysis. Geometrically-corrected digital satellite imagery provides a cost-effective means for incorporating resource data into the planning and management processes (Henderson, 1984; Ihemadu, 1985). Digital satellite data has been used to evaluate the vegetation component of habitats for mammals, such as moose in Alaska (Laperriere et al., 1980) and Manitoba (Dixon et al., 1984), caribou in the Northwest Territories (Thompson et al., 1980), and grizzly bear in Montana and Alaska (Craighead et al., 1985). Digital terrain data has mainly been used as a tool in habitat mapping to improve classification accuracy of digital satellite data (e.g. Hutchinson, 1982). For example, Craighead et al. (1982) used digital terrain data to separate Landsat-derived vegetation zones by elevation for the mapping of grizzly bear habitat in Montana.

To achieve truly representative habitat maps for alpine mammals, relevant ancillary terrain data (elevation, slope magnitude, and slope azimuth) must be incorporated into the habitat classification and mapping process. A study conducted by Stefanovic and Wiersema (1985) in the European Alps, demonstrated the utility of digital terrain data for modeling insolation as the principal parameter in alpine ibex habitat. Terrain parameters were more important to this species of wild goat than vegetation types (Stefanovic and Wiersema, 1985). Similarly, Dall's sheep distributions are also considerably influenced by terrain parameters (Nichols, 1978). After an exhaustive search of the literature, only one example could be found of the digital mapping of terrain and land-cover components of habitat using integrated satellite image data and terrain data. Bonner et al. (1982) used elevation, slope magnitude, and Landsat-derived vegetation data sets to produce a map of potential bighorn sheep habitat.

Most of the published literature concerning the incorporation of digital satellite data into habitat mapping has utilized summer imagery to provide vegetation information. Comparatively little work has been undertaken using digital winter imagery for snow-cover mapping. Snow cover is one of the most significant factors governing the survival of northern ungulates (Formozov, 1946; Pruitt, 1959; Skogland, 1978; Telfer and Kelsall, 1979), and thus the identification of snow-free areas is imperative information needed for proper management practices (Jaques, 1982). Wiersema (1983), in a study focused on ibex habitat, employed three techniques for detection of snow-free areas in a Landsat Multispectral Scanner System (MSS) scene acquired over the French and Italian Alps. These techniques included: (1) an unsupervised approach to digital classification to locate snow-free migration routes; (2) a visual interpretation of Landsat band 5 (red) brightness maps to determine snow-cover boundaries and transient snow lines; and (3) a visual interpretation of false colour composites to locate snow-free vegetated areas. Jaques (1982) investigated four techniques for identifying non-forested snow-free areas as potential critical winter habitat for native ungulates in the Rocky Mountains of Alberta using Landsat MSS data. The four image analysis techniques were: (1) the visual interpretation of color infrared composite images; (2) single theme density slicing for each MSS band; (3) an unsupervised approach to multispectral cluster analysis; and (4) a multitemporal classification approach where a summer scene was used to classify non-forested areas and a winter scene was used to identify snow-free areas. Jaques (1982) concluded that the fourth approach produced the most accurate maps of critical winter range.

Dall's Sheep Winter Habitat

Dall's sheep along with Stone's sheep (*Ovis dalli stonei*) are subspecies of the thinhorn species (*Ovis dalli*) of North American sheep (Nichols, 1978). Dall's sheep are found in Alaska, the Yukon Territory, the Northwest Territories, and the extreme northwestern part of British Columbia (Nichols, 1978). The Yukon Territory contains the "largest wild sheep population of any jurisdiction in Canada" (Hoefs and Barichello, 1985:16). Hoefs and Barichello (1985) estimated the Dall's sheep population in the Yukon Territory at 19,000.

Dall's sheep habitat lies almost entirely above tree line and consists of steep, dry, south-facing grassland slopes interspersed with broken cliffs and talus slopes (Geist, 1971; Hoefs, 1974; Nichols, 1978; Hoefs and Cowan, 1979). There are four major parameters that define Dall's sheep winter habitat (Hoefs, pers.comm., 1987; Barichello, pers. comm., 1987): (1) moderate to steep slopes, (2) south-facing slopes, (3) snow-free vegetated areas, and (4) proximity to escape terrain (Geist, 1971; Hoefs, 1974; Nichols, 1978; Hoefs and Cowan, 1979). These parameters have all been previously expressed in qualitative terms. This thesis addressed the first three parameters defining winter habitat using digital terrain data and satellite data.

The vegetation types associated with Dall's sheep winter habitat were not examined in this study. The major vegetation types consumed by Dall's sheep are associated with dry, exposed, alpine grasslands (Hoefs and Cowan, 1979). These grassland associations are found mainly on south-facing slopes, and therefore the identification of the vegetation component is a consequence of the identification of south-facing slopes. The fourth parameter, proximity to escape terrain, was also excluded from this project. Digitally defining and quantifying escape terrain is a complex process and warrants a separate study. No such study has yet been attempted.

Winter is one of the most critical times in the life cycle of Dall's sheep. From late winter until spring very little food is available and the sheep depend heavily on stored body fat for nutritional needs. During this period the population is concentrated in areas where snow-free feeding sites are found in close proximity to escape terrain (Nichols, 1978; Hoefs and Cowan, 1979). Winter range is limited by snow conditions to a very small portion of the overall range (Nichols, 1978). In early winter the snow is soft and sheep can paw through to the vegetation (Geist, 1971; Nichols, 1978; Hoefs and Cowan, 1979). In late winter, however, the snow is often wind packed and impenetrable. Consequently, in late winter sheep depend on the steep, south-facing, and/or wind-scoured ridges that remain snow free (Nichols, 1978; Hoefs and Cowan, 1979), making this the critical time to detect snow-free areas.

Watson/Wheaton Study Area

The study area is situated within the planning region designated by the Yukon Department of Renewable Resources as the Watson/Wheaton Pilot Project. A helicopter survey conducted within this region during March, 1987 served as the basis for this research. The study area is located approximately 25 km south of the city of Whitehorse, and is bounded in the south by the British Columbia/Yukon Territory border. Located between latitudes 60°00' and 60°30' north and between longitudes 134°44' and 135°48' west, this 3267 km^2 area encompasses approximately one quarter of the National Topographic Series (NTS) 1:250,000 map 105D. Dimensions of the study area are 55 km in the north-south direction by 59.4 km in the east-west direction.

Situated within the Coast Mountains Ecoregion (Oswald and Senyk, 1977), the terrain is very rugged, ranging in elevation from 650 m asl at Lake Bennett to over 2500 m asl in the southern part of the mountains with several ice-covered peaks above 2400 m asl. The Coast Mountains Ecoregion falls within the discontinuous scattered permafrost subzone, much of the areas lies above treeline (Oswald and Senyk, 1977), and the climate is subarctic continental (Wahl et al., 1987). A low sun angle and long winter nights are typical for this latitude with less than six hours of sunshine received on December 21 at a maximum solar elevation of 6° (Wahl et al., 1987).

In Carcross, the nearest meteorological station to the study area, the average annual snowfall is 101.3 cm, with most snow falling between November and March (Table 1). January is the coldest month with temperatures averaging -19.8 °C (range -15.1 °C to -24.8 °C). The mean March temperature is -8.3 °C (-1.8 °C to -14.8 °C) with a mean snowfall of 10.2 cm (Atmospheric Environment Service, 1982a). Average snow-depth data is not available for Carcross.

Table 2 contains a summary of the weather data for March 1987, the period pertaining to this study. The mean temperature during March, 1987 was -12.0 °C (range 6.0 °C to -35.5 °C) with 7 cm of snow falling for a total snow depth of 15 cm (Atmospheric Environment Service, 1987). According to Wahl et al. (1987), snow depths reach their maximum by early to mid-April at elevations greater than 1000 m in the southern part of the Yukon Territory. The closest meteorological station with wind data is Whitehorse. In March, the prevailing wind direction varies from southeast to south, with average wind speeds of 19.7 km/h from the southeast and 17.2 km/h from the south (Table 3). Dominant wind directions over the interior Yukon Territory coincide mainly with the valley orientations (Wahl et al., 1987).

TABLE 1
Average Climate Data for Carcross, Yukon Territory (1951-1980)

	Month												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Daily maximum temperature (°C)	-15.1	-7.7	-1.8	5.6	11.5	16.7	18.9	17.9	12.3	5.1	-3.9	-11.2	4.0
Daily minimum temperature (°C)	-24.8	-18.7	-14.8	-5.9	-0.5	4.6	6.4	4.9	1.4	-3.2	-12.0	-19.8	-6.9
Daily mean temperature (°C)	-19.8	-13.2	-8.3	-0.2	5.5	10.7	12.7	11.4	6.9	0.9	-7.9	-15.5	-1.4
Rainfall (mm)	0.2	1.0	0.0	1.8	11.5	14.9	19.2	21.2	19.8	12.8	4.7	11.6	118.7
Snowfall (cm)	24.2	17.8	10.2	4.3	0.3	0.4	0.0	0.0	2.4	4.8	18.2	18.7	101.3
Total * precipitation (mm)	19.4	16.5	12.6	6.5	11.8	15.0	19.2	21.2	21.8	20.4	22.9	24.1	211.4
Days with precipitation	6	6	4	2	4	6	7	7	7	7	8	8	72

* Rainfall + water equivalent of snowfall.

Source: Atmospheric Environment Service (1982a).

TABLE 2
March, 1987 Weather Summary for Carcross, Yukon Territory

Snowfall (cm)	7.0
Snowdepth (cm)	15.0
Maximum temperature (°C)	6.0
Minimum temperature (°C)	-35.5
Mean temperature (°C)	-12.0

Source: Atmospheric Environment Service (1987).

TABLE 3
Average March Wind Data for Whitehorse, Yukon Territory (1953-1978)

Wind direction	% frequency	Average wind speed (km/h)
NNE	0.6	12.3
NE	0.3	6.3
ENE	0.1	9.7
E	0.5	10.6
ESE	1.6	18.0
SE	14.9	19.8
SSE	17.8	20.2
S	14.7	16.8
SSW	2.3	16.1
SW	2.4	11.9
WSW	1.6	10.9
W	3.2	8.7
WNW	2.3	9.9
NW	11.4	13.6
NNW	6.7	14.9
N	7.3	13.5
Calm	12.3	
All directions		14.3

Source: Atmospheric Environment Service (1982b)

III. DATABASE DEVELOPMENT

Digital Terrain Data

Digital topographic information in the form of a generated grid of elevations or a digital elevation model (DEM) was required for this research. A portion of a 1:250,000 National Topographic Series (NTS) map was digitized using the Interactive Graphic Design System (IGDS) software developed by the Intergraph Corporation, running on a VAX-11/730 minicomputer. Each 500 foot contour was digitized using point mode sampling. Large flat areas were supplemented by digitizing additional contours and points from 1:50,000 NTS maps of the area.

The digitized lines, comprised of X and Y coordinates and their associated Z (elevation) values, resulted in a total of 27383 sets of triplets. To create a regular grid of elevation values, these triplets were surfaced using a multiquadric equation algorithm based on an analytical interpolation approach developed by Hardy (1971) and implemented in roving form by Eyton and Hemenway (1987). The number of calculations performed by this surfacing routine is quite extensive; approximately 23 hours of CPU time on a VAX-11/730 were required. The resulting DEM contained 550 rows and 594 columns with each grid cell covering a 100 m by 100 m area on the ground. Multiquadric surfacing was used because the equations were designed for topographic expression where the fitted surface must pass through all of the observation points exactly (Hardy, 1971). The DEM was then smoothed once using a low-pass spatial filter to remove local irregularities. Figure 1 shows a perspective plot of the smoothed DEM. Latitude, longitude, and north are indicated on this figure. Where appropriate, the rest of the figures are oriented with north at the top.

Derivative products obtained from the DEM supplied the necessary information regarding landscape geometry. Slope magnitude and slope azimuth data sets were derived from the smoothed DEM using an algorithm developed by Eyton (1987a). This algorithm employs the method of finite differences applied to a 3 x 3 neighborhood to obtain the slope magnitude and slope azimuth components of the first spatial derivative. The derived data sets were identical in size and locational reference to the original grid of elevation values. These data sets were used to quantify the first two parameters defining Dall's sheep winter habitat: slope magnitude and slope azimuth. A hillshaded map, based on a Lambertian reflectance model (Eyton, 1988), was created from the slope and azimuth data sets and used as a map base for most of the illustrations presented in this study.

Habitat Polygons

Dall's sheep winter habitat areas (polygons) were delineated on a 1:100,000 topographic map during a helicopter survey conducted by Yukon Territorial Government biologists on March 19 and 25, 1987. The helicopter survey covered all known winter ranges of Dall's sheep within the study area (Hoefs, pers. comm.,

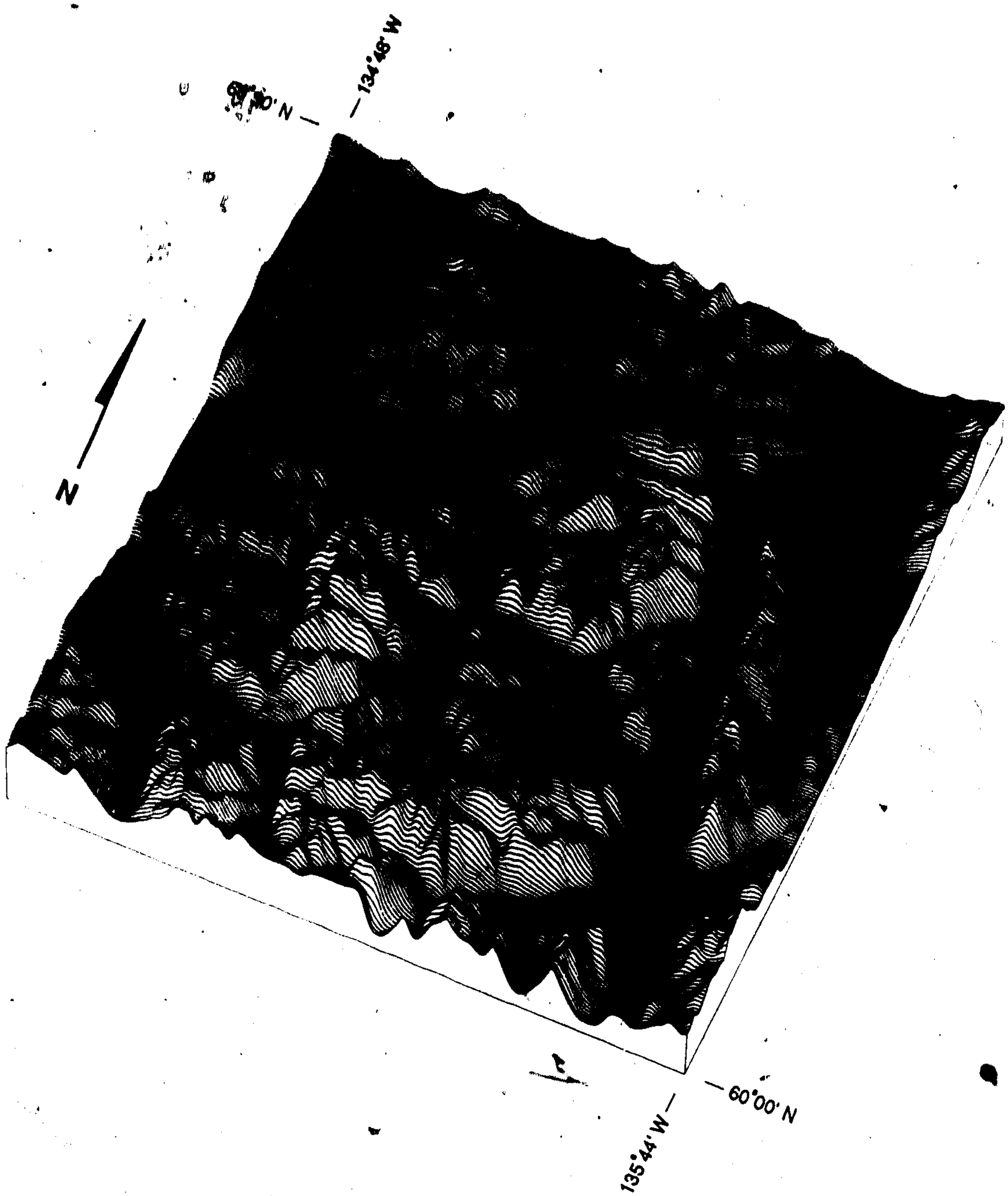

FIGURE 1. Perspective plot of the smoothed DEM (with 5X vertical exaggeration) of the Watson/Wheaton study area, Yukon Territory. The viewing perspective is from the SSE (azimuth=157.5°) at an observer altitude of 60°.

1987). This survey was described by Hoefs (pers. comm., 1987) as a complete but low intensity survey; the entire area was flown, but with only a single pass. In this survey, the locations of the polygons were based on sightings of sheep or concentrations of tracks. The field expertise of the biologist was of paramount importance in determining the polygon boundaries. Areas which Yukon biologists indicated were marginal winter habitat were excluded from this study.

Forty-eight polygons from the 1:100,000 map were digitized, and a binary (sheep/no sheep) digital mask was produced using a vector-to-raster procedure (Eyton, 1987b). The digital mask registered with the digital terrain data sets. Figure 2 shows the digital mask overlaid on the hillshaded map to indicate the location of the Dall's sheep winter habitat polygons. The digital mask was used to extract information for the winter habitat polygons from the digital elevation model and from the slope magnitude and slope azimuth derivative models.

Landsat Data

A Landsat Thematic Mapper (TM) image (#51111-193421) was obtained for March 17, 1987. The satellite pass occurred two days prior to the winter aerial survey from which the sheep winter habitat polygons were delineated. The Landsat digital data was used to identify snow-free areas within the study area. The image data was initially processed using the CAL 3 linear radiometric calibration process at the Prince Albert Satellite Station. This

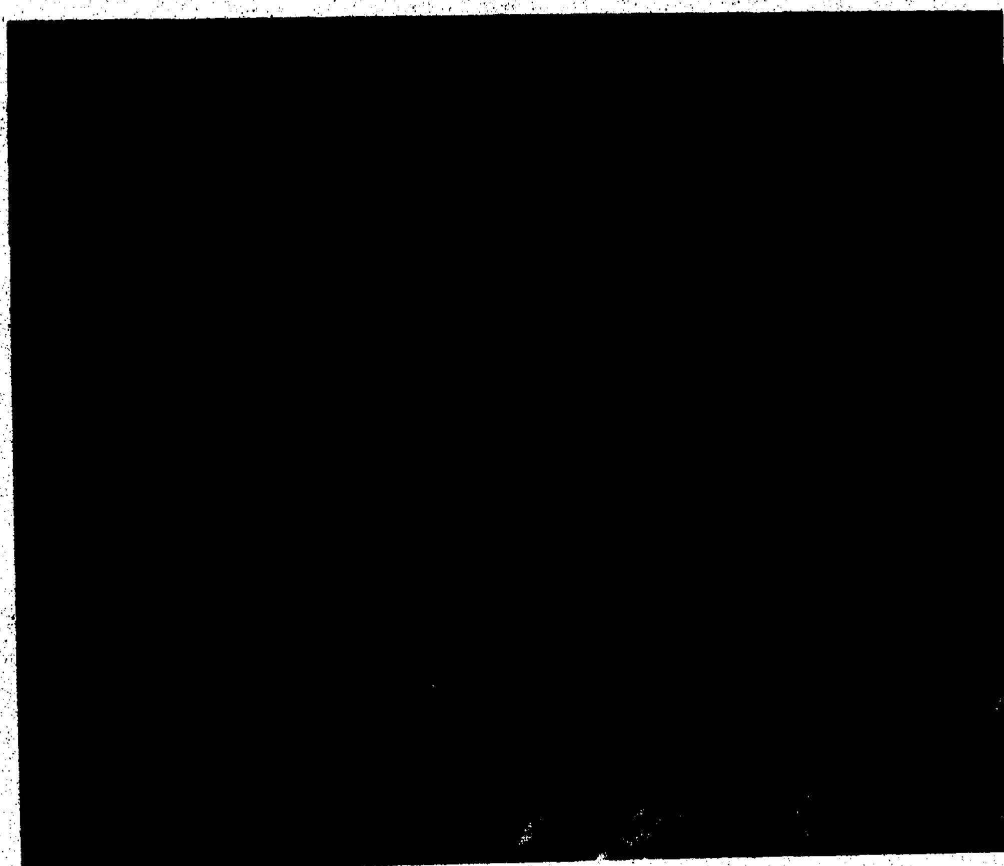

FIGURE 2. Digital mask overlaid in black on a hillshaded map of the Watson/Wheaton study area, Yukon Territory. Illumination is from the northwest (azimuth=315°) at a solar altitude of 45°.

procedure retains the majority of the dynamic range of brightness values, providing improved coverage of bright and dark extremes (Ahern and Murphy, 1978; Ahern, 1979; Ahern et al., 1987). To achieve registration with the other digital data sets, the image quadrant was subset and geometrically corrected to a Universal Transverse Mercator projection. The pixels were resampled to 100 m grid cells using nearest-neighbor interpolation; overall accuracy of the registration was approximately 33 meters (the difference between the estimated and the actual row and column coordinates of the 18 ground control points in the original image). The nearest-neighbor method "is the preferred technique if the new image is to be classified since it then consists of the original pixel brightnesses, simply rearranged in position to give a correct image geometry" (Richards, 1986:53). These transformations were conducted at the Alberta Remote Sensing Center using the DIPIX LCT-11 (ARIES 11) digital image analysis system.

The Landsat TM quadrant encompassed the majority of the study area, excluding the extreme northeast corner. Data dropouts in lines or groups of pixels were present in all bands due to equipment failure during transmission from satellite to receiving station. One particularly large dropout, 16 entire lines, was flagged to indicate missing data.

IV. ANALYSIS AND MAPPING OF DALL'S SHEEP WINTER HABITAT

Two objectives of this research were to quantitatively define (1) the terrain limits, and (2) the snow-free areas for Dall's sheep winter habitat. Once these quantitative parameters were established, a map overlay and intersection process was used to achieve the third and final objective; (3) the identification of potential sheep winter habitat areas in the study area. A brief overview of the procedure is given below to clarify the detailed discussion which follows.

The digital mask, indicating the location of Dall's sheep from the March, 1987 aerial survey, was used to extract the slope magnitude and slope azimuth values characterizing sheep habitat from the terrain data sets. These distributions were first plotted as histograms and the limits defining the range of each distribution was determined by removing outliers. These outliers were likely due to measurement error, however, even if they were not, removal was justified because there is a low probability of their occurrence. The limits defining the maximum and minimum of this range are called clipping levels or threshold values. This project involved the overlay and intersection of multiple data layers, therefore, a liberal approach for determining clipping levels was adopted. The slope magnitude and slope azimuth ranges, and snow-free sites characterizing sheep winter habitat were then used to identify potential winter areas within the study area for sheep which were not identified in the March, 1987 aerial survey.

Slope Magnitude

The distribution of slope magnitude values for each grid cell of the study area (Figure 3a) shows an abundance of gentle slopes and comparatively few steep slopes. Within the study area there is a marked concentration of slopes with less than 10° magnitude and a very low frequency of slopes above 45°. The steepest slopes within the region are approximately 56° magnitude. A gray scale map of the slope magnitude distribution for the entire area is shown in Figure 4.

The slope magnitude distribution characterizing sheep winter habitat (Figure 3b) differs markedly from the distribution of slope magnitude for the entire study area (Figure 3a). The histogram in Figure 3b shows a positively skewed distribution, a pronounced mode with a frequency of 4.4% occurring at 23°, and a large variation about the mode. Removal of data outliers was accomplished by excluding slope values having a frequency of occurrence of less than 1% resulting in approximately 2% and 4% of the slope magnitude observations being excluded from the left and right ends of the distribution, respectively. This 1% frequency cutoff produced a slope magnitude range of 3° to 37°. This range was characteristic of approximately 94% of the Dall's sheep winter habitat area (Table 4). Grid cells with values between 3° and 37° were extracted from the slope magnitude data set and displayed as a black tone. The boundaries (in white) of the sheep winter habitat polygons were overlaid on the single-class map shown in Figure 5. This map shows the areal extent of

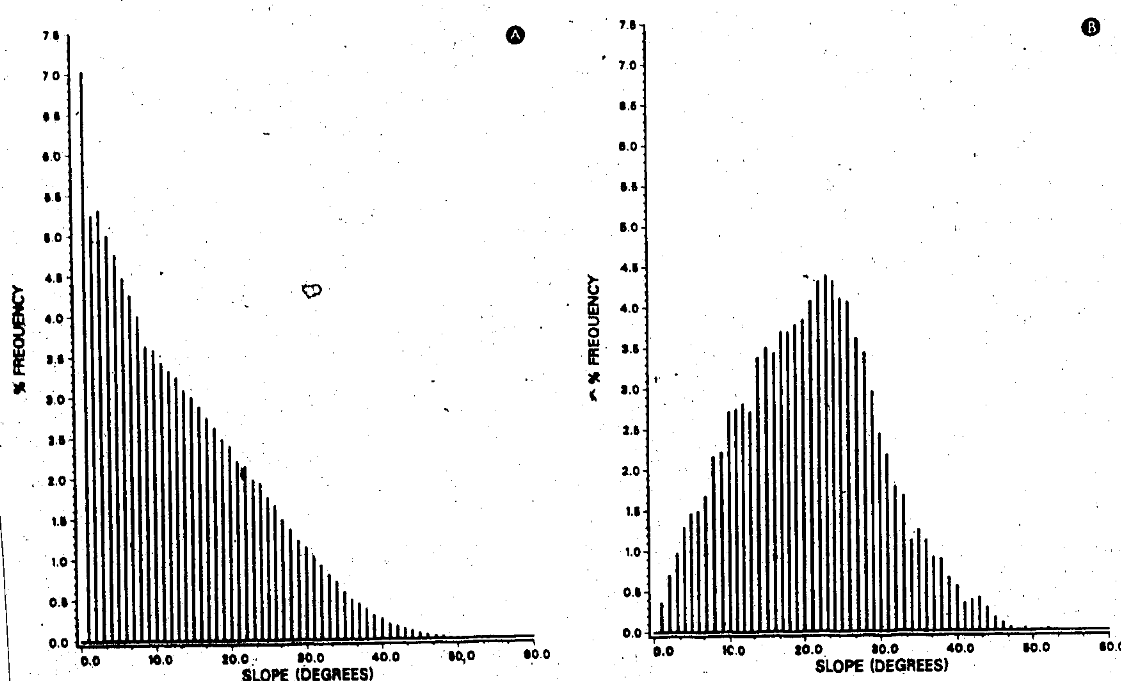

FIGURE 3. Frequency distributions of slope magnitude for (a) the entire study area, and (b) the sheep winter habitat polygons.

FIGURE 4. Gray scale map of the slope magnitude distribution for the study area. Light tones indicate steep slopes and dark tones indicate gentle slopes.

TABLE 4
Areal Extent of Habitat Parameters

Habitat parameter(s)	%of polygon area accounted for by habitat parameter	% of study area encompassed by habitat parameter
Slope magnitude*	94.1	80.7
Slope azimuth**	70.4	37.6
Snow-free, non-forested areas	12.1	9.6
Slope magnitude*/ slope azimuth**	68.7	30.6
Slope magnitude*/slope azimuth**/snow-free, non-forested areas	4.9	1.5

* range: 3° - 37°
** range: 110° - 260°

FIGURE 5. Single-class map of the study area showing the distribution of slope magnitude characterizing Dall's sheep winter habitat in black. The boundaries of the habitat polygons are overlaid in white.

the slope magnitude range characterizing sheep winter habitat. The range of acceptable slope magnitude values is quite large, encompassing 81% of the study area (Table 4), thus slope magnitude was not an important parameter for defining winter habitat within this area. The slope magnitude range, however, did eliminate some areas from consideration as potential sheep winter habitat in the last part of the analysis.

Slope Azimuth

The percent frequency of grid cells (covering the entire study area) for each degree of slope azimuth was plotted as a circular histogram (Figure 6a). The distribution indicates that the topography is not predominantly oriented in a specific direction, however, there is a slight tendency for slopes to be northwest or southeast oriented. A gray scale map of slope azimuth for the entire area is shown in Figure 7. This gray scale map illustrates the global variation of slope azimuth within the study area and corroborates what is shown in the histogram; no dominant orientation is apparent.

The frequency of slope azimuth grid cells characterizing Dall's sheep winter habitat were plotted as a circular histogram in Figure 6b. In contrast to Figure 6a, this graph exhibits a very pronounced trend of south-facing slopes, especially southwest-facing slopes. Inspection of the graph indicates two primary modes occurring at 127.5° and 142.5° with approximately 3.5% frequency of occurrence for each mode. Four secondary modes

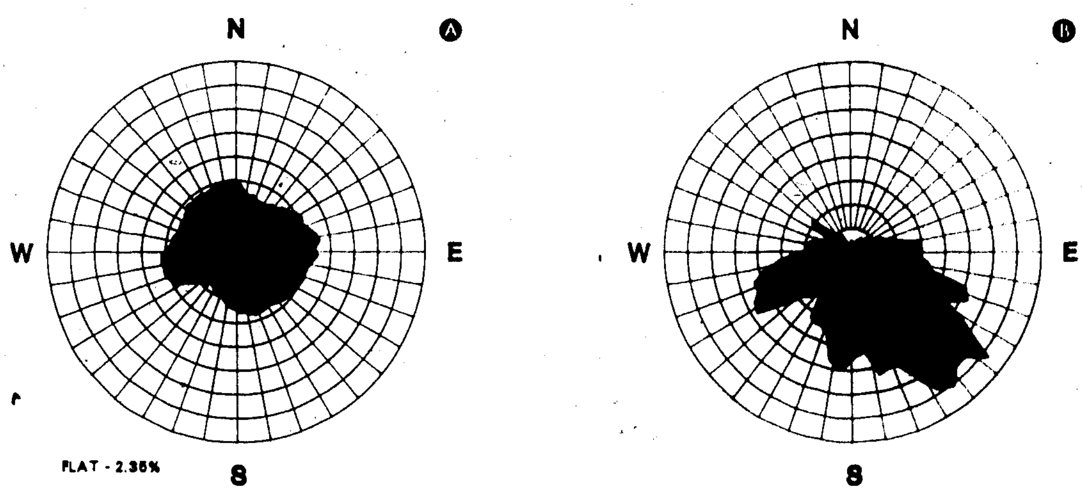

FIGURE 6. Frequency distributions of slope azimuth for (a) the entire study area, and (b) the sheep winter habitat polygons. The radial lines represent 10° intervals of slope azimuth, the radial rings represent 0.5% frequency intervals, and the outer ring indicates 4% frequency.

FIGURE 7. Gray scale map of the slope azimuth distribution for the study area. North-facing slopes are black, west-facing slopes are dark gray, east-facing slopes are medium gray, south-facing slopes are light gray, and flat areas are white.

are also evident (112.5°, 167.5°, 187.5°, and 237.5°) with approximately 2.5% frequency of occurrence for each mode. On the basis of the biologists' helicopter survey, it appears that sheep winter habitat is characterized by southwest- to southeast-facing slopes. Clipping levels of 110° and 260° (determined by simple inspection of the graph) were used to map the slope azimuth range describing winter habitat. Approximately 70% of the Dall's sheep winter habitat area was accounted for by the slope azimuth range (Table 4). Those grid cells contained within the clipped range were displayed as a single-class map overlaid on the hillshaded map with the boundaries of the sheep habitat polygons added in white (Figure 8). Slope azimuth may be a stronger controlling factor than slope magnitude for the winter distribution of sheep because the slope azimuth distribution is better defined from the observational data than the slope magnitude distribution. The clipped slope azimuth range encompassed 38% of the study area (Table 4).

Snow-free Sites

Snow-free sites were identified by level slicing (thresholding) Landsat TM band 1 (blue) data. The blue band was used because the shorter wavelengths are scattered more than the other wavelengths of visible radiation that interact with gas molecules in the earth's atmosphere (Lillesand and Kiefer, 1979). The scattered light present in the scene illuminated those areas in shadow enabling the detection of snow-free surfaces. Snow/no

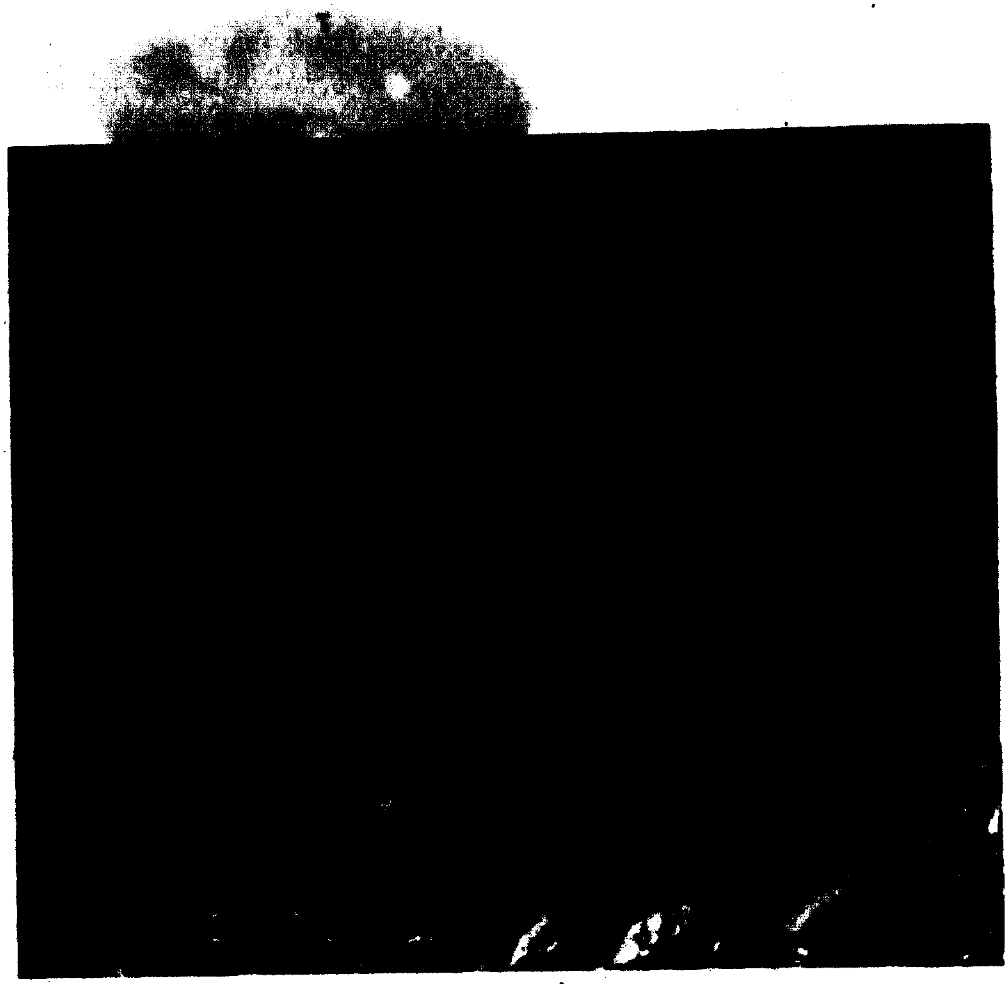

FIGURE 8. Single-class map of slope azimuth range defining Dall's sheep winter habitat overlaid in black on the hillshaded map of the study area. The boundaries of the habitat polygons are added in white.

snow pixels were identified and located on a line-printer brightness map of TM band 1 data. Color photographs acquired during the March (1987) helicopter survey, single band images of each of the 7 Landsat bands, and normal color and color infrared composites were used as aids in this process. The threshold of snow was determined by examining the brightness values of individual pixels from representative samples of snow/no snow interfaces within the scene. Brightness values below 150 indicated snow-free areas and brightness values above 150 indicated snow-covered areas.

Non-forested, snow-free areas were difficult to distinguish from forested areas by level slicing. The mislabeling of forested sites as non-forested, snow-free sites was reduced by eliminating forested sites from the snow-cover labelling. The elimination of these sites was justified because Dall's sheep winter habitat lies above tree line (Nichols, 1979; Hoefs and Cowan, 1979). The upper limit of tree line occurs at approximately 1050 m within the study area (Oswald and Senyk, 1977). Using the DEM and the Landsat band 1 data, image grid cells with brightness values less than 150 and elevation grid cells with values greater than 1050 m were classified as snow free and non-forested. The locations of snow-free, non-forested pixels are shown in black on the hillshaded map (Figure 9). The boundaries of the sheep winter habitat polygons were overlaid in white on the single-class map to show the location of the polygons relative to the snow-free, non-forested areas. Only 9.6% of the area covered by the Landsat image was snow free on March 17, 1987 (Table 4). Much of this

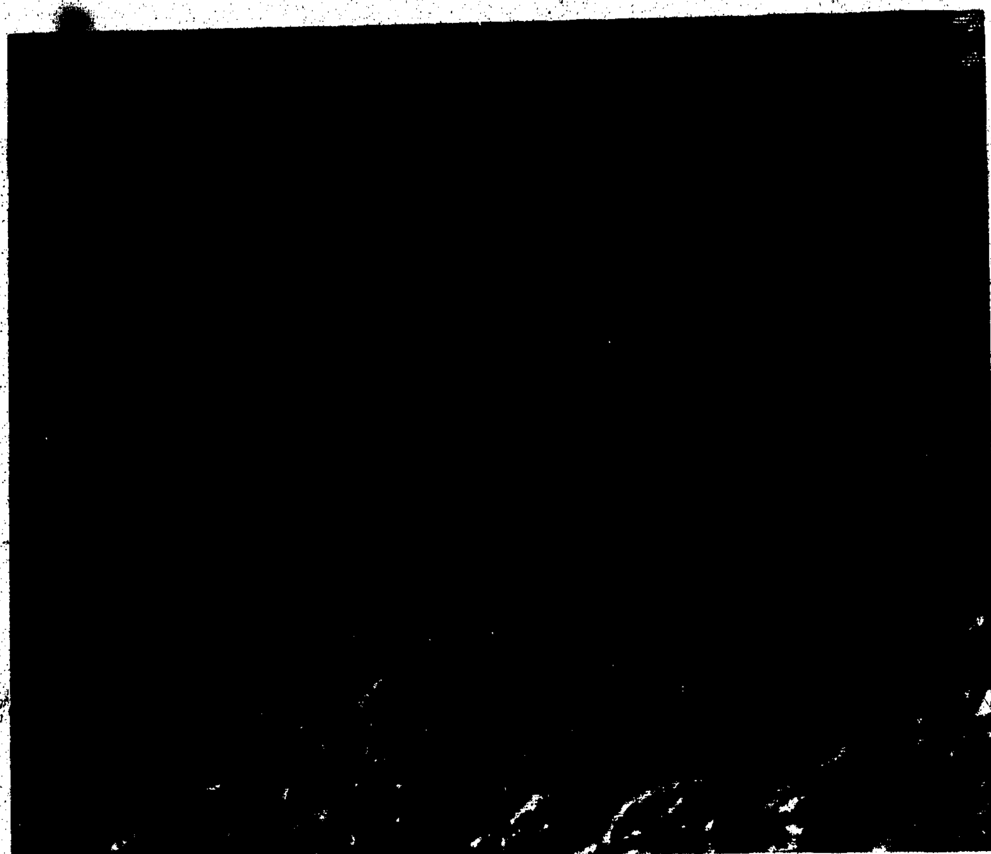

FIGURE 9. Single-class map of snow-free, non-forested sites shown in black overlaid on the hillshaded map of the study area. The boundaries of the habitat polygons are overlaid in white on the single class map.

area, however, occurs within shadow and may not be snow free. The elimination of shadowed areas will be discussed later.

The digital mask was used to quantitatively define the characteristics of Dall's sheep winter habitat in terms of the areal extent of the snow cover. Approximately 12% of the area covered by the habitat polygons was snow free (Table 4). The northernmost polygon was excluded from the analysis as it fell outside of the area covered by the Landsat image. When each polygon was considered individually, only 16 of the 47 polygons exceeded a frequency of 10% snow free (Table 5); most of the polygons contained very few or no snow-free pixels. The snow-free parameter was not a significant factor in defining Dall's sheep winter habitat for this area at this time of year.

Snow depth cannot be ascertained using a single Landsat scene. Inferences concerning the depth of snow can be made as follows: (1) the presence of snow-free pixels within polygons may be indicative of thinning snow within those polygons, (2) the presence of snow-free pixels adjacent to polygons may be indicative of thinning snow within nearby polygons, (3) the absence of snow-free pixels within polygons or adjacent to polygons may indicate snow depth was not a controlling factor at this time of year. As shown in Figure 9, the majority of polygons met the first condition indicating that a majority of the polygons may contain thinning snow.

TABLE 5
Frequency of Snow-free Pixels for Habitat Polygons

Habitat polygon	Snow-free pixels	Total pixels	% frequency snow-free
1	19	66	28.79
2	9	34	26.47
3	19	106	17.92
4	1	47	2.13
5	2	40	5.00
6	3	34	8.82
7	16	27	59.26
8	0	363	0.00
9	14	65	21.54
10	23	251	9.16
11	10	320	3.13
12	97	97	100.00
13	6	92	6.52
14	23	140	16.43
15	85	421	20.19
16	41	426	9.62
17	27	168	16.07
18	3	255	1.18
19	1	148	0.68
20	4	59	6.78
21	10	144	6.94
22	0	157	0.00
23	2	265	0.75
24	8	63	12.70
25	13	54	24.07
26	15	223	6.73
27	2	224	0.89
28	441	1286	34.29
29	56	95	58.95
30	23	73	31.51
31	3	64	4.69
32	5	70	7.14
33	24	273	8.79
34	2	346	0.58
35	20	278	7.19
36	56	654	8.56
37	8	614	1.30
38	11	190	5.79
39	0	59	0.00
40	3	71	4.23
41	7	79	8.86
42	31	305	10.16
43	39	153	25.49
44	1	305	0.33
45	0	106	0.00
46	4	289	1.38
47	0	226	0.00

Identification of Potential Sheep Winter Habitat Areas

The process of map overlay and intersection of the terrain distributions and the snow-free distribution was employed to produce two maps: (1) a slope magnitude and slope azimuth intersection map, and (2) a slope magnitude, slope azimuth, and snow-free intersection map. The intersections of the defined ranges of slope magnitude (3° - 37°) and slope azimuth (110° - 270°) characterizing sheep winter habitat were overlaid in black on the hillshaded map shown in Figure 10. The boundaries of the sheep habitat polygons in white were also included. This map differs very little from Figure 8 (the single-class map of slope azimuth) but differs markedly from Figure 5 (the single-class map of slope magnitude) indicating again that slope azimuth is a more significant controlling factor than slope magnitude. The combination of these 2 parameters encompassed 31% of the study area (Table 4). Sixty-six percent of the sheep winter habitat area was accounted for by the defined ranges of the combined slope azimuth/slope magnitude map. Those polygons which did not fall within the slope magnitude and slope azimuth ranges may be explained by other factors discussed later.

Map overlay and intersection of the slope azimuth and slope magnitude terrain distributions and the snow-fr[illegible]istribution was used to create the single-class map shown in Figure 11. The single-class map was overlaid in black on the hillshaded map along with the boundaries of the sheep habitat polygons. The

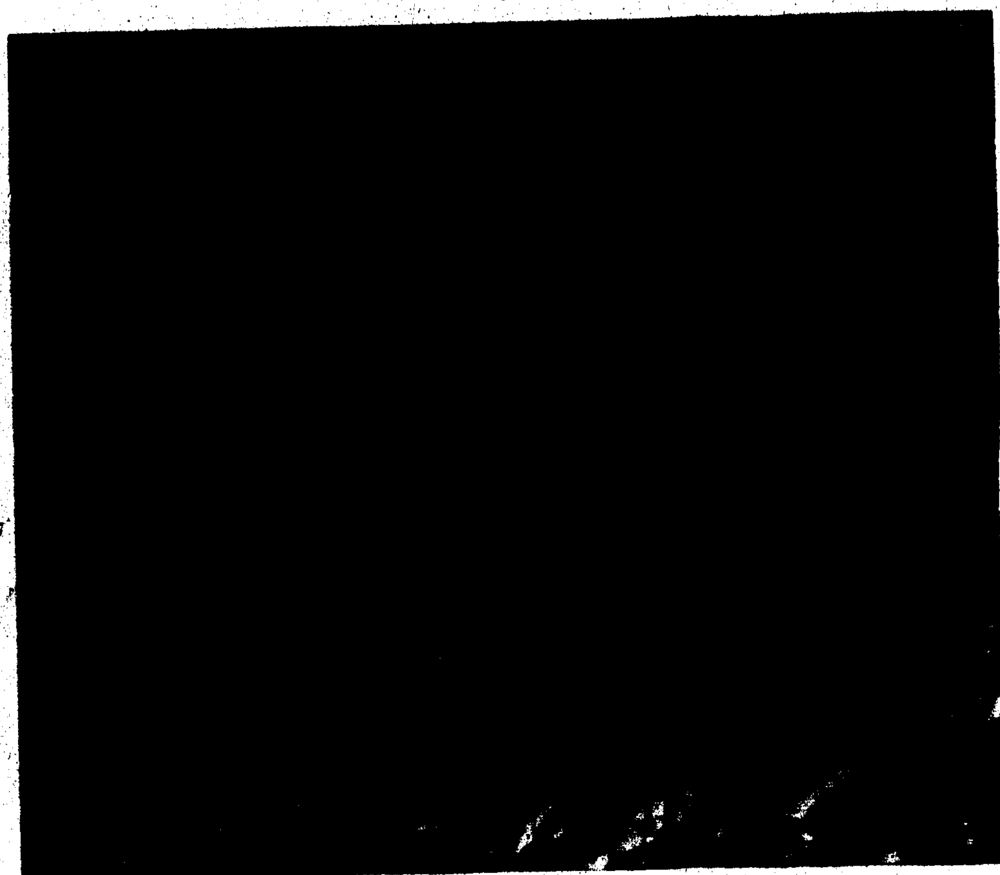

FIGURE 10. Single-class map of slope magnitude and slope azimuth ranges characterizing Dall's sheep winter habitat overlaid in black on the hillshaded map of the study area. The boundaries of the habitat polygons are overlaid in white.

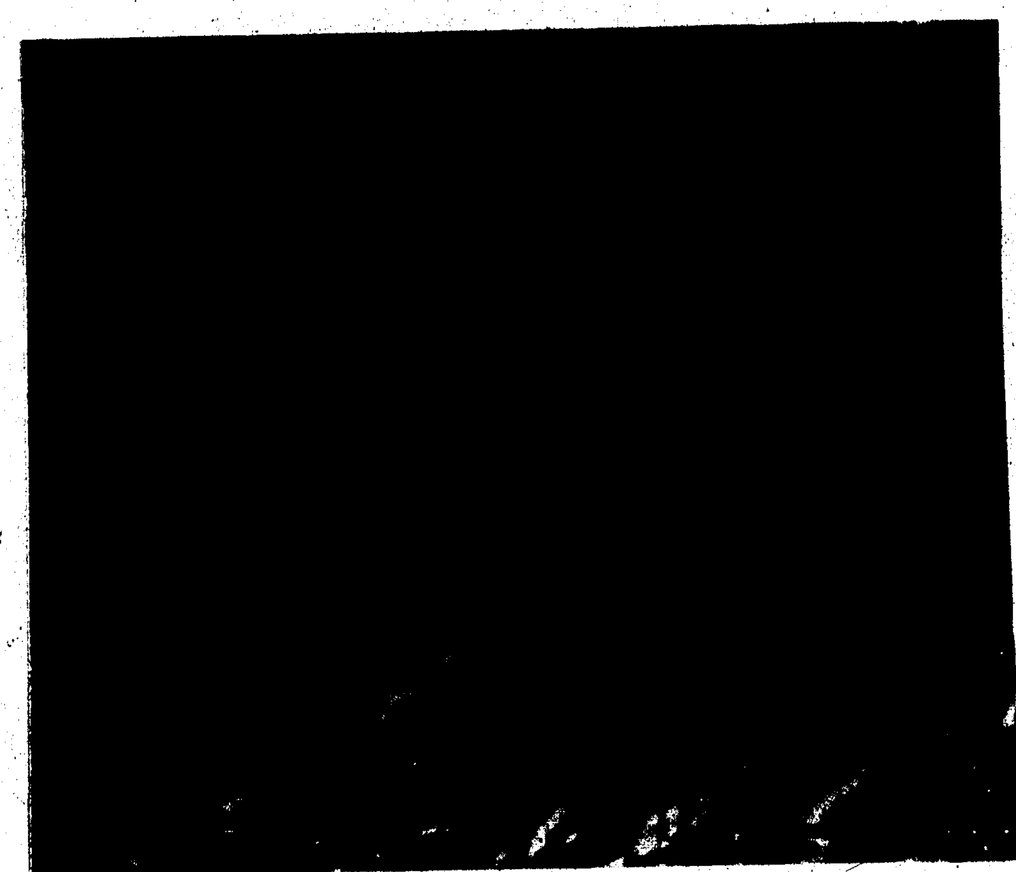

FIGURE 11. Single-class map of slope magnitude and slope azimuth ranges characterizing Dall's sheep winter habitat in conjunction with the snow-free, non-forested sites. The single class is shown in black on the hillshaded map of the study area and the habitat polygons are shown as white boundaries.

defined ranges of these parameters accounted for 5% of the sheep winter area (Table 4). Very few areas fell within the slope magnitude and slope azimuth range characterizing Dall's sheep winter habitat that were also snow free. This combination essentially removed shadowed areas (north facing) from the snow-free, non-forested binary map (Figure 9), to produce a map representing the actual snow-free areas (1.5% of the study area - refer to Table 4).

Snow depth was probably a greater controlling factor than absence or presence of snow in determining Dall's sheep winter habitat. Sheep can paw through snow to the vegetation if the snow is soft and shallow (Geist, 1971; Nichols, 1978; Hoefs and Cowan, 1979). The snow depth in March, 1987 was only 15 cm and the mean temperature (-12 °C) was well below freezing (Table 2). The snow was likely thin and relatively soft allowing the sheep to penetrate the snow cover to reach the underlying vegetation.

Landsat data may be useful for identifying probable areas of shallow snow if a temporal analysis strategy is adopted. Those areas that were snow free before or after the helicopter survey date were likely thinner than other areas. The snow was probably shallow around the snow-free areas, therefore snow-covered pixels adjacent to snow-free pixels likely contained thinning snow. Landsat data was not recorded for the study area immediately before the survey date and the image acquired immediately after the survey date was cloud covered, consequently this approach could not be tested. Without multitemporal imagery, it is not possible to distinguish between thin snow and deep snow using possible to distinguish between thin snow and deep snow using Landsat data.

Slope azimuth appears to be the dominant controlling factor describing Dall's sheep winter habitat in the study area. The importance of slope azimuth is due to the relationship of vegetation, insolation, and wind to slope azimuth and the influence of insolation and wind on snow cover. The vegetation types consumed by sheep are found mainly on south-facing slopes which receive greater than usual insolation. In addition, the resulting melting combined with sublimation reduce the snow cover on these slopes. The predominant wind direction for March varies from the southeast to the south (Atmospheric Environment Service, 1982b), thus slopes with a south to southeast orientation will become wind blown resulting in thinner snow cover and snow-free sites.

The overall objective of this research was to develop spatial analysis techniques that would be useful for mapping Dall's sheep winter habitat. Figure 10 shows the best estimate of areas (in black) that meet the established criteria for Dall's sheep winter habitat. These potential habitat areas are based on the defined ranges of slope magnitude (3° - 37°) and slope azimuth (110° - 260°). Although untested at this time, the mapping of potential sheep habitat areas may be useful (1) to predict areas for sheep relocation, (2) to provide information for input into land use decisions, (3) to implement protective measures for sheep habitat, (4) to assist habitat managers in planning flight routes for winter aerial surveys, and (5) to increase the understanding of Dall's sheep habitat.

V. SUMMARY

A method for habitat mapping and analysis using digital satellite data and digital terrain data has been presented. This method was used to quantitatively evaluate the three of four major parameters that define Dall's sheep winter habitat in a 3287 km area, located south of Whitehorse, Yukon Territory. The four major parameters are: (1) moderate to steep slopes, (2) south-facing slopes, (3) snow-free vegetated areas, and (4) proximity to escape terrain.

Slope azimuth and slope magnitude terrain data sets were developed and used to evaluate the first two parameters defining Dall's sheep winter habitat. The third parameter, snow-free areas, was identified using Landsat TM band 1 data registered to a regular grid of elevation values. The fourth parameter, proximity to escape terrain, was not investigated.

The process of map overlay and intersection was employed to identify potential sheep winter habitat areas. The results were as follows:

(1) Slope magnitude was not a limiting factor in determining Dall's sheep winter habitat ($3^\circ - 37^\circ$), however, the slope magnitude range eliminated some areas from consideration as potential habitats. The slope magnitude range encompassed 81% of the study area and accounted for 94% of the sheep winter habitat area.

(2) Slope azimuth was the dominant controlling factor in determining Dall's sheep winter habitat. This parameter accounted

for 70% of winter habitat polygons and encompassed 38% of the study area. Southwest- to southeast-facing slopes (110° - 260°) characterize sheep habitat. The dominance of slope azimuth is due to the relationship of vegetation, insolation, and wind to slope direction and the influence of insolation and wind on snow cover. The vegetation types consumed by sheep are found mainly on south-facing slopes. South-facing slopes receive intense insolation resulting in reduced snow cover due to sublimation and melting. Due to the predominant southern wind during March, south-facing slopes become wind blown resulting in shallow snow and snow-free sites.

(3) Snow-free areas were not a significant factor for defining Dall's sheep winter habitat. Snow-free areas accounted for 5% of the winter habitat area and encompassed 1.5% of the study area. Snow depth may be a factor, but multitemporal Landsat imagery is required to identify probable areas of shallow snow. This technique could not be tested because multitemporal imagery was not available for the Watson/Wheaton planning region during the winter of 1987.

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