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ANALYSIS USING SATELLITE DATA.

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FEASIBILITY OF CARIBOU WINTER

HABITAT ANALYSIS USING SATELLITE DATA

A

THESIS

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FEASIBILITY OF CARIBOU WINTER HABITAT ANALYSIS USING SATELLITE DATA

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ABSTRACT

This study was concerned with evaluating feasibility of using satellite multispectral scanner data (LANDSAT) for caribou habitat and vegetation mapping employing a variety of visual and digital processing techniques.

Visual techniques were useful for synoptic analyses of broad general vegetation types such as forest or tundra. These types were usually too general to permit useful wildlife habitat evaluations but the mapping of recent wildfire burns is an exception. This could be accomplished over large areas each year and would be rapid and inexpensive.

Techniques which involve computer processing of LANDSAT data in digital tape format allow rapid detailed mapping of specific vegetation associations over large areas. Qualitative interpretations of these associations as wildlife habitat are possible.

Two specific processing algorithms were evaluated; supervised interactive classification and unsupervised non-interactive classification. If was concluded that unsupervised non-interactive processing is more practical for large scale Alaskan applications.

LANDSAT data were used to map winter ranges of the Porcupine caribou herd in northeast Alaska. Data on vegetation and animal utilization of different vegetation types in this area were obtained

through ground surveys. Analysis of these data indicated that fruticose lichens are the most important component of winter range for caribou in northeast Alaska.

A classification of caribou winter range was proposed that distinguished sustaining and occasional types. Sustaining winter ranges are open lichen woodlands dominated by white spruce (*Picea glauca*). Occasional winter ranges are treeless upland areas of lichen-rich tundra which are grazed only in certain years apparently depending upon variation in snow conditions.

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Finally, a significant contribution was made by my capable field assistants: Mr. Robert Pelz, Mr. Fred DeCicco, Mr. Tom Kron, and Ms. Sharon Kessey.

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INTRODUCTION

I. Remote Sensing

The objective of this investigation was to determine feasibility of applying remote sensing data to wildlife biology research and management in Alaska. In particular, the study addresses the feasibility of using LANDSAT data in applications relating to caribou biology and management. The original name of the satellite, Earth Resource Technology Satellite (ERTS-1), was changed to LANDSAT in 1975.

Remote sensing is simply the study of objects at a distance, e.g., earth, lunar, and planetary surfaces. The first hunter who climbed a tree to look for game utilized operational remote sensing. Therefore, application of the remote sensing concept antedates recorded history. The first significant technological advance in remote sensing was Galileo's (1564-1642) invention of the telescope. Operational remote sensing involving the use of photography, however, is only about 50 years old (McEwen 1972). The Department of Agriculture has used aerial photography since about 1935 principally for field mapping (Von Steen 1972). Foresters have used remote sensing since 1921 when visual aerial surveys from seaplanes were made in Canada and the northwestern United States to map the extent and severity of an insect infestation destroying valuable spruce and fir forests (Heller 1972). Forest managers have been using aerial photography for over 30 years for all stages of natural resource management: location of timber cutting areas, in-place inventories for timber, recreation sites, range, wildlife, water, and fire-fuel mapping (Heller 1972).

During World War II, radar was developed to increase the range and resolution of detection. This development was the first major conceptual innovation since Galileo and resulted in recognition of the utility of other ranges of electro-magnetic radiation for detection and identification of specific target objects. Further technical evolution ensued with the realization that the spectral signature concept could be applied in remote sensing. This concept is the basis of spectroscopy and, while it has been useful in nuclear chemistry and physics for a number of years, its application in remote sensing has been confined to astronomy until recently.

During the past 30 years, technical improvement and extensive application of these "new" concepts has occurred, and continued technological improvement can be expected through the next century or longer. Because there are no indications that further major conceptual innovation is imminent, the developments are continuing improvement of instrumentation and integration of more sophisticated sensors with other technological advances requiring increasingly complex data collection/processing systems. Operational applications should be greatly expanded throughout this technical development. These include recent application of the multispectral signature concept using multiband line scanners.

II. The U. S. Satellite Program

The beginnings of operational environmental satellites occurred in April 1960 with the launch of the first Television Infrared Observation Satellite (TIROS I). Their success initiated accelerated evolution of new spacecraft and sensor systems. In general, the decade of the 1960's was one of primarily meteorological and communications applications for operational satellites. Spacecraft in a variety of orbits and equipped with progressively more sophisticated sensor packages evolved. Concurrently, applications to oceanography and hydrology began early in the 1970's, and this decade marks the approximate beginnings of an explosive expansion of remote sensing technology and its application to diverse disciplines. Recent applications have included mineral exploration, geothermal exploration, environmental pollution detection, cartography, traffic analyses, soils mapping, water quality studies, human population census, land use inventory, fisheries research, agricultural crop surveys, rangeland research, and wildlife ecology.

A. LANDSAT Satellite

In July of 1972, the first LANDSAT satellite was launched. It operated in a circular, sun synchronous, near polar orbit at an altitude of about 500 nautical miles. The satellite circles the earth every 103 minutes, completing 14 orbits each day, and it views the entire globe every 18 days. LANDSAT was launched with an anticipated life expectancy of 12 to 18 months. However, in late 1975 it was still functioning and obtaining data after three years.

The LANDSAT sateliite is the first of a series in the Earth Resources Observation Satellites (EROS) program. The objectives of EROS are to develop and launch operational satellites with the capability of monitoring the earth's resources. Success of the program would permit comprehensive, timely resource inventory on a global scale.

The first two satellites of the EROS program were intended to be experimental prototypes preceding the fully operational EROS satellites. Applied research with data generated by the LANDSAT satellites is scheduled for use in design modifications of the operational satellites.

1. Sensors

LANDSAT has two sensor systems and a relay system, namely, a four channel multispectral scanner (MSS), a three camera Return Beam Vidicon (RBV), and a Data Collection System (DCS).

a. MSS System

The MSS system simultaneously obtains reflectances in four discrete bands of the electromagnetic spectrum:

Band	Range
4	.5 to .6 microns
5	.6 to .7 microns
6	.7 to .8 microns
7	.8 to 1.1 microns

Bands 4 and 5 are in the range of visible light whereas bands 6 and 7 are in the near infrared range.

Each set of four scanner measurements is called a picture element ("pixel"). The size of a particular pixel depends upon spacecraft altitude and relative speed which are a function of geographic latitude. Additional variability in pixel size depends upon pixel position in the scan line and this variability is a function of earth curvature. Variation in pixel size is relatively small on any particular scene, however, and over Interior Alaska, the unique area (Figure 1) covered by a given pixel is approximately .49 ha. This compared with approximately .47 ha over the midwestern United States.

These figures, however, are not pixel "size" or the surface area for which reflectance measurements are obtained, because a process called spectral inter-leaving is utilized in data collection. This process provides a 10% overlap of pixels with nearest neighbors and thus assures complete and partially repetitive coverage of the earth surface (Figure 1). Therefore, reflectances in a given pixel set over Interior Alaska do not correspond to .49 ha of surface but rather to a larger area approximately .65 ha in size. Moreover, pixels are not square but are rectangular parallelograms with the short side of the rectangle oriented approximately northeast-southwest (030°-210°). Therefore, reflectance measurements of a pixel set over Interior Alaska correspond to a rectangular area of earth surface approximately .65 ha in size.

MSS data are presented in blocks which comprise a LANDSAT scene. There is some variability in scene size, but scenes are approximately 100 nautical miles by 96.4 nautical miles or approximately 10,000 square nautical miles in size. An average scene is composed of 3200 rows of pixels by 2340 scan lines. That is, a LANDSAT MSS scene is a data matrix which is 3200 by 2340 by 4 containing about 30 million discrete reflectance measurements.

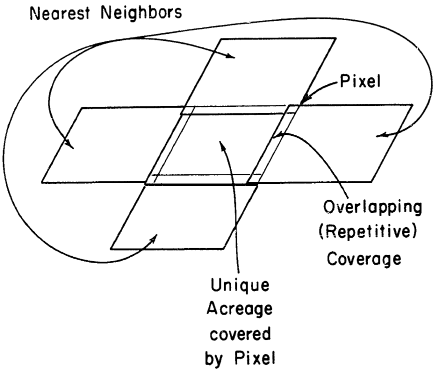


Figure 1. Surface area covered by LANDSAT (ERTS) multispectral scanner pixels.

Although the scanner sweeps rapidly, pixel sets are discrete non-simultaneous measurements. The four measurements for any given pixel set are simultaneous, but no pixel set is simultaneous with any other pixel set. Because of this, geometric distortions are introduced but application of 14 basic geometric corrections reduces distortion to an order of magnitude of about 1:1,000 (Colvocoresses 1974). RBV is a camera system which obtains pictures which are geometrically more accurate than scanner data but their spectral resolution is lower.

b. RBV System

The RBV system is a three camera system designed to obtain data in three spectral regions. Each camera is equipped with different spectral filters to provide separate viewing regions which are:

Band	Range
1	.475 to .575 microns
2	.580 to .680 microns
3	.698 to .830 microns

Unfortunately, an electronic malfunction developed five days after launch and the system was turned off by ground control, but some data were obtained over Alaska in late July 1972. However, these data seemed less useful than MSS data for wildlife habitat analyses.

c. DCS System

The DCS system is simply a relay system. Ground based instruments located in remote areas transmit data in coded format to the satellite during overpass. Data are retransmitted or relayed to ground receiving stations where they are processed for delivery.

2. Data Handling

Three ground stations are part of NASA's Space Tracking and Data Network (STDN). These are located at Fairbanks, Alaska; Goldstone, California; and Greenbelt, Maryland. Data acquired by the satellite are normally telemetered simultaneously to one of these ground stations. Data which are obtained at great distances from ground stations (Africa, South America, etc.) are stored and later transmitted to ground receiving stations.

3. Data Processing and Products

NDPF processes incoming data by applying corrections and making video tape to film transformations. Subsequent photographic products are forwarded to the EROS Data Center at Sioux Falls, South Dakota, where they are made available to the public.

LANDSAT data may be purchased from the EROS Data Center at Sioux Falls in a variety of formats. Photographic formats include 70 mm single band film chips (positive or negative), 1:1,000,000 scale single band positive transparencies, 1:1,000,000 scale single band paper prints, and 1:1,000,000 scale false color composite (bands 4, 5, and 7) positive transparencies or paper prints. Digital data formats include 7 or 9-track computer compatible digital tapes.

III. Purposes of the Investigation

The objective of this investigation was to determine and report the feasibility of applying LANDSAT data to wildlife management tasks in Alaska with particular reference to caribou biology. Within the framework of this broad general objective, application potential for the following specific tasks was assessed: (1) mapping of seasonal snowcover; (2) detection of disturbed snowcover in caribou feeding areas; (3) detection of heavily used caribou trail systems; (4) detection of large aggregations of caribou; and (5) analysis and mapping of caribou winter range (Lent and LaPerriere 1974). The rationale for these tasks will be discussed individually.

The purpose of mapping seasonal snowcover conditions was to achieve a more complete understanding of the factors influencing chronology and routing of caribou migrations. This task is related to Pruitt's (1959) "snow fence" hypothesis and, if LANDSAT data could provide a synoptic view of snow conditions, Pruitt's hypothesis might be supported or disproved in a relatively few years. Correlation of the chronology and route utilization of caribou migrations to snow conditions over a large area would significantly contribute to increased understanding of migratory patterns for specific herds.

Detection of disturbed snowcover in caribou feeding areas would provide indication of winter range utilization in a particular year by seasons such as late fall versus early spring utilization. This information, if collected over a sufficient period of years, might reveal whether or not there is any cyclic periodicity to caribou winter range utilization. An additional practical advantage is that the information could be a useful adjunct to field research operations. For example, knowledge of the approximate location of wintering animals could save many hours of reconnaissance flying by field biologists, especially if LANDSAT imagery was made available rapidly.

Detection of both heavily used caribou trail systems, particularly differentiation between trails utilized and unutilized in a given year, and large aggregations of caribou would increase knowledge of summer movement patterns.

Analysis and mapping of caribou winter range could contribute to long-term management as well as research. Identification of specific geobotanical associations and evaluation of each in terms of range value could result in a map of potential range for use in land selections and long-term, land-use planning. Mapping of burned areas immediately after the fire season could provide rapid annual assessment of the caribou-moose range situation over large areas. During the non-fire season, plans for moose and caribou range management based on selective firefighting effort could be formulated. Certain areas could be identified as critical caribou winter range and assigned the highest priority for firefighting effort. Other areas might be identified where small burns might be desirable and these areas could be assigned a lower firefighting priority.

IV. The Porcupine Caribou Herd

A caribou herd has been defined as a group of animals that calve at the same approximate geographic location each year but perhaps mingle with animals of adjacent herds at other times of the year (Skoog 1968). Hemming (1971) describes 6 major herds, 5 minor herds, and 2 introduced herds in Alaska. Of these, the Porcupine herd is currently the second largest. Recent surveys report a population size of approximately 100,000 animals (LeResche 1973).

It is an international herd with animals ranging over portions of Northeast Alaska, the Yukon Territory, and a small portion of the Northwest Territory during various seasons of the year (Hemming 1971). Hemming (1971) stated: "Caribou have occurred within the present range of this herd for at least 100 years." Seasonal distributions reported for the late 1800's (Funston 1896, Murie 1935, Preble 1908, and Russel 1898) were quite similar to more recent reports (Hemming and Pegau 1970, LeResche 1975, McEwan 1952a, Olson 1958, 1959, Renewable Resources 1973, Scott 1953a, Skoog 1968, Soper 1951, and Stevens 1948). However, it was not suggested that the animals of this region were part of a single herd until 1953 (Scott 1953b).

The usual winter range of most of these animals is the northern Ogilvie Mountains and the head of the Porcupine River, but some animals winter in Alaska in the Arctic Village--Chandalar area (LeResche 1972). Little use is normally made of the Arctic Slope in most winters but isolated reports of caribou on the North Slope in winter do exist (Hemming 1971, Lent 1966, Olson 1959). Movement onto winter range areas may continue into December and adult males tend to penetrate further to the south than conspecifics (Hemming 1971). Some animals remain scattered over winter range areas throughout the winter whereas other groups exhibit somewhat regular movement patterns during the winter (Hemming 1971).

The spring migration northward normally begins in March (Hemming 1971). Adult cows comprise the vanguard of spring migratory movement while bulls and many yearlings follow at a leisurely pace with some lingering on winter ranges until June (Hemming 1971, LaPerriere personal observations 1972, 1973). Although varying numbers of caribou may move northward along the Dietrich and Middle Fork of the Chandalar River in some years, most of the passes in northeast Alaska west of the Kongakut are precipitous containing glaciers and heavy snow which present a barrier to migratory movement (Hemming 1971). Consequently, most herd animals move north utilizing low passes to the east along the Blow, Babbage, and Firth rivers (Hemming 1971). Deep snow and unseasonable severe weather may delay migratory progress resulting in calving occurring en route (Hemming 1971, LaPerriere personal observation 1972). On one occasion part of the herd calved near Arctic Village and extremely high calf mortality resulted from the unseasonable weather (Scott 1953b). However, this is relatively unusual and delays in migratory progress more commonly result in the occurrence of some calving along the Canadian coast between Herschel Island and the Alaskan border (McEwan 1952b, Stevens 1948).

The major calving area utilized by the Porcupine herd consists of the Arctic coastal plain between the Katakturuk and Babbage rivers (LeResche 1975). Calving begins about May 30, and ends in June (Skoog 1962).

Soon after calving, cows and new calves assemble into increasingly larger groups (Hemming 1971). In early July of 1972, a very large loose knit aggregation comprising the majority of the herd assembled south of Camden Bay between the Katakturuk and Hulahula rivers (LaPerriere personal observation). This group numbered upwards of 82,000 animals (LeResche 1973) and appeared to reach maximum concentration about the 1st or 2nd of July (Hemming personal communication). All sex and age classes seemed to be represented in the aggregation and dispersion began to occur about July 5 (LaPerriere personal observation). A similar event occurred in July 1973 when animals reached maximal concentration and began to disperse on approximately the same dates as in the preceding year (Roseneau personal communication). This concentration of animals during the first week of July is the norm and considered an annual occurrence (Hemming personal communication, Thayer personal communication).

Hemming (1971) reported that some bulls and yearlings are scattered throughout the summer on both sides of the Brooks Range from Atigun-Dietrich Pass eastward into Canada and "in late summer, most of the herd may be found along the coastal range from the Arctic National Wildlife Range eastward to the Blow River." He suggests that the majority of the herd move into Alaska only during calving and return to Canada for the remainder of the summer. Some animals do appear to remain in Alaska throughout the summer, however, and Roseneau (personal communication) suggests there is some regularity to their movement pattern. In both 1972 and 1973, he observed significant numbers of animals passing the vicinity of Arctic Village in mid-August. These animals had arrived from the northeast and were gradually drifting southwest. They continued this movement until reaching the approximate vicinity of the Middle Fork of the Chandalar in late August. The direction of movement was then reversed and the animals passed the vicinity of Arctic Village again in September moving to the northeast. Still another reversal of direction occurred in late October and numbers of animals moved southwest again to reach the vicinity of Arctic Village where they remained throughout the winter. He observed similar movement patterns in both 1972 and 1973. Whether these events suggest a distinct Alaska subpopulation of the herd or simply are random occurrences is a question that may only be answered by further research.

A. Range Use

Caribou movements are extremely complex and the herds are almost constantly in motion (Hemming 1971, Kelsall 1968). Primary migrational patterns seem to be governed by seasonal energy demands (Hemming 1971). Klein (1970) reported that the greatest dietary requirements occur in spring and summer when the animals must fulfill the demands of calving, lactation, antler development, and molt. Hemming (1971) concluded that movement patterns at that time are usually directed towards areas of the most abundant and best quality forage.

Although some periodicity and pattern are evident in both seasonal and daily movements, animals may visit some areas almost annually but utilize others only once in a decade (Hemming 1971). Moreover, small herds often demonstrate only limited seasonal movements and, as caribou density increases, animals extend their movements farther and farther into marginal areas from the most favorable portion of their range (Banfield 1951, Lent 1966, Skoog 1968). At times of extremely high population density, movements become erratic and herds may split apart or join with others unpredictably (Kelsall 1968, Skoog 1968). Finally, various events may influence migratory or local movement patterns in any given year. For example, insect harassment in midsummer tends to keep caribou aggregated (Kelsall 1968) and they may seek relief on windswept ridges or on remnant patches of snow or ice (Hemming 1971).

Summer forest fires influence movements of caribou and newly burned areas are usually avoided (Hemming 1971, Scotter 1970). Snow conditions affect distribution local movement, feeding patterns, and migratory activity (Avranchik 1939, Formozov 1946, Henshaw 1968, Nasimovich 1955, Pruitt 1959, Skoog 1968). A great deal remains to be learned about the life history of the caribou and their role in the northern ecosystem. Movement patterns, range utilization, population fluctuations, and many other aspects of caribou biology remain only partially understood.

1. Characteristic Winter Range

Caribou and reindeer often move to winter ranges where there is more tree cover and this is believed to be related to the greater availability of food in those areas (Bergerud 1971, Formozov 1946, and Hemming 1971). These boreal forest areas are usually characterized by coniferous trees at relatively low density, a tall shrub understory consisting primarily of *Salix* and *Betula*, and ground cover which contains a significant amount of fruticose lichens and mosses (Helsall 1968, Skuncke 1969).

Caribou and reindeer are specially adapted physiologically to utilize lichens as a primary food source in winter (Klein 1970). They must dig through the snow to obtain this forage. Formozov (1946), Bergerud (1974), and Miller (1964) content that the animals are able to locate lichens through snow cover by olfaction. Formozov stated that many lichens in moist condition, particularly *Cladonia*, have a strong pungent odor which may even be detected through snow cover by a man. Additionally, snow in the forest areas is usually less dense than in open windswept areas which enables the caribou to dig through the snow for lichens and other vegetation.

Associations or correlations between snow cover and vegetation types have been reported (Sandberg 1958). Various agricultural studies have demonstrated that snowmelt patterns influence growing conditions (e.g., Staple and Lehane 1955). Snowmelt characteristics at a particular site are influenced by wind-packing, wind erosion, shading, and disturbance. Caribou feeding activity on winter range influences the spring snowmelt at these sites which melt off sooner than undisturbed sites. This, in turn, probably affects growing conditions. These complex interrelationships between existing vegetation, prevailing nival characteristics, and caribou are incompletely understood.

2. Influence of Snow

Pruitt (1959) hypothesized that "herds of caribou are actually the summation of individuals and bands aggregated because of the 'fencing' or restricting action of snow. The discreteness of the several 'herds' is but a biological reaction to areas or channels of softer, lighter and thinner snow cover between and among areas of harder, denser, and thicker snow cover." Other investigators have reported findings which tend to support this hypothesis (Bergerud 1971, Henshaw 1968, Lent 1966, Miller 1974).

Taiga or breal forest areas with snow accumulations greater than 50 or 60 cm are avoided by free ranging animals (Formozov 1946, Pruitt 1959). Pruitt (1959) defined ideal snow conditions for caribou winter range to be depths not exceeding 50 or 60 cm, density not exceeding 0.20 in feeding areas, hardness not exceeding 60 g/cm^2, continuous low temperatures during the snow season, and low wind speeds. The latter two requirements are related to the formation of ice crusts and wind packing. Obviously, both ice crusts and wind packing hinder feeding activity of animals that must dig through snow cover to obtain food. However, depending upon its depth, hardness and the type of substrate, shallow wind-packed snow in windswept areas may be easier to dig through than deeper snow in forest areas. This may be the factor involved in some exceptions to the generalization that caribou winter in forested areas. Ice crusting may become a serious hindrance to feeding activity and travel because such crusts produce injuries to the animals' legs (Formozov 1946). Pegau (1968) considers ice crusts 3.8 cm to 5.1 cm thick the upper limit of caribou tolerance. That is, caribou cannot survive over winter on ranges where such ice crusts usually form.

3. Effects of Fire

Forest fires have a marked effect on caribou lichen winter range. The removal of trees destroys wind sheltering thus opening these areas to wind drifting and packing of snow cover. More important, however, is the destruction of lichens by fire in the ground cover which, when dry, burn readily. Regrowth of these lichen stands requires considerable time. Pegau (1968) reported average linear annual growth rates of *Cladonia* species preferred by reindeer to vary between 4.3 and 5.8 mm. Scotter (1967) states: "It usually takes from 70 years to more than a century for the major forage lichens to recover [from fire] to their former abundance and composition . . . ." Skuncke (1969) described effects of fires in Sweden where *Cladonia alpestris* was still completely absent even 140 years after burning. Lutz (1956) suggested that lichen recovery may take from 20 to 50 years or more. Therefore, the effect of fire on lichen stands is complex and the time required for recovery depends on a variety of factors such as the extent of the damage caused by a fire, climatology of the site, the vegetational association existing at the time of the fire, and the substrate. For example, a wind driven "crown fire" occurring under conditions of relatively high surface moisture might produce little or no damage to ground cover lichens.

Scotter (1970) states: "Fires in the southern limits of the winter range of barren-ground caribou are sometimes beneficial in destroying thick carpets of bryophytes in certain upland forests thereby making them more productive for lichens and other forest plants." Also, Ahti and Hepburn (1967) suggested burning of Sphagnum fuscum peatlands, treeless bogs, and wooded muskegs in the northern boreal lichen belt of Ontario would increase the lichen supply.

Some authors, however, disagree with the premise that lichens are an essential or even necessary component of caribou winter range (Bergerud 1972). Johnson and Rowe (1975) contend that fires are a natural phenomenon to which caribou have adapted and they suggest that fires may even be beneficial to winter range by renewing growth of sedges, forbs, and shrubs. In their arguments, they cite Jakimchuk et al. (1974) who reported caribou wintering in areas without extensive lichen range.

Kelsall (1968) reported that caribou avoided recently burned forest areas and that these areas deflected migrations. He further noted that lichen-poor areas of early fire recovery succession would be avoided if alternate ranges were readily available. Scotter (1970) and Kelsall (1968) reported that the best caribou forage production occurred in mature forest which had not been burned for 120 years or more. In Scotter's (1970) investigations, the number of caribou pellet groups per acre was highest in mature stands unburned for 120 years or more.

Consequently, the effect of fire on caribou winter range depends upon specific circumstances, but most range scientists would agree that summer forest fires are usually destructive of caribou winter range (Kelsall 1968).

METHODS

I. General

Several LANDSAT data formats are available. A systematic, progressive data handling plan was devised to cope with them. For example, a specific task would be attempted by simple visual interpretation of a single band image. If this was not feasible, the task would be attempted with single band density slicing, analysis of false color composite imagery, or processing of digital tape data, respectively, as required. That is, tasks were attempted using progressively more complex, costly, and powerful techniques until a suitable technique was discovered.

The initial basis for data interpretation was generalized knowledge of existing conditions from direct observation or ground-truth. During the course of the investigation, however, general ground truth based on oblique aerial photography and qualitative field notes of the investigator proved an inadequate basis for satisfactory interpretation of LANDSAT data, and especially for detailed comparison of various analytic techniques. Often, evaluations were inconclusive and the oblique photography could not be used easily for accurate location of ground points. Therefore, methods for collecting more detailed ground truth were adopted and these included ground survey of selected test sites as well as low altitude, multispectral photography.

Test sites were selected to represent accurately a single target feature. These test sites were used as standards for interpretation of LANDSAT data and attempts were made to detect and/or map all similar targets on the LANDSAT data. In the case of digital data, test sites became the basis for training sets, that is, those reflectance measurements in the LANDSAT data matrix corresponding to a particular test site were used as a training set for that target feature. Based upon training set data, discriminations were identified by applying discriminant analysis to all available training sets. Decision algorithms were then used to classify or categorize much larger portions of the data matrix and produce maps of desired target features where feasibility was indicated. These feature maps were later verified by systematic grid sampling of randomly selected areas.

II. Ground Truth Data Collection

Within the context of this presentation in relation to LANDSAT imagery, ground based sampling, low level aerial photography, and aerial reconnaissance are all considered ground-truth. The entire area considered in the investigation consisted roughly of Alaska and the Yukon Territory north of about 63° north latitude. However, our ground truth data collection was confined primarily to northeast Alaska, defined by that area north of the Porcupine River between 141°W and 148°W. Ground truth for other areas was provided by the Canadian Wildlife Service, the U. S. Fish and Wildlife Service, the Alaska Department of

Fish and Game, and Renewable Resources Consulting Services, Ltd., a private consulting firm.

A. Ground Truth Provided by Cooperating Agencies

1. Canadian Wildlife Service provided ground truth consisting of aircraft reconnaissance reports of caribou aggregations in the Yukon Territory during the summer of 1972.

2. U. S. Fish and Wildlife Service provided ground truth consisting of reports of animal distribution and aerial photography of test sites.

3. Alaska Department of Fish and Game provided ground truth consisting of caribou trail system and vegetation maps of portions of the Alaskan Arctic coastal plain.

4. Renewable Resources, Ltd., provided ground truth consisting of aircraft reconnaissance reports of animal distribution.

B. Ground Truth Collected by the Investigators

1. Vegetation

a. Site Selection

Test site areas for vegetation sampling were selected by aerial reconnaissance and analysis of air photos. Criteria used were size, apparent homogeneity of vegetation, proximity to a readily identifiable geographic feature such as a lake or river, and reasonable accessibility by float plane.

Some investigators dislike working with training sets containing less than 100 pixels (Cummings personal communication, Rogers personal communication) because they prefer a relatively large statistical sample, but the nature of their investigations permits selection of large training sets. A training set containing 100 pixels over Interior Alaska would correspond to a surface area exceeding 48 ha. For certain types of target features such as agricultural fields, large lakes, and extensive urban areas, it would be possible to select test site areas of that size or larger. Unlike these types of targets, however, wilderness vegetation seldom occurs in large contiguous uniform blocks. Therefore, some compromise was required in site selection and it was decided to select sites which were approximately 28 hectares in size if possible, but not less than 16 hectares and not less than 300 m on a side. These sites are large enough to be associated with at least 25 to 30 pixels, which is a reasonable sample in light of observed variability (Harbo personal communication, Frohne personal communication). The shape of test sites was square or rectangular and configuration varied to fit within the pattern of the existing vegetation type target. For example, some sites were 400 x 400 m, whereas others were 300 x 1000 m.

Apparent uniformity of vegetative cover, based on low level aerial reconnaissance, was a key criterion in test site selection. Selection of targets representing a single type of vegetation association was attempted. However, this ideal was almost never realized. For example, a stand of white spruce might actually contain small clearings, ponds, or differences in tree size and density which were not evident from aerial reconnaissance.

Proximity to a readily identifiable geographic reference point was also an important consideration in test site selection. In this context, we do not refer to precise cartographic location but rather to location of the selected reference point in the LANDSAT data matrix. Hydrologic features such as lakes and rivers are most suitable because they are easily located in LANDSAT data matrices. Lakes larger than 4 ha. in size or major rivers were used, and then specific points such as the confluence of two drainages or a characteristic shoreline feature were selected as the reference points for on-the-ground survey of test sites. Because of this procedure, some sampling bias against high alpine areas was inevitable. However, unless test sites can be located with reasonable accuracy in the LANDSAT data matrix ground data collection is pointless. Similar sampling bias occurred because sites were selected within a reasonable distance to float plane access points, usually within 5 kilometers. However, the geographic reference and float plane access were often identical because prominent lakes and rivers were used for geographic location on LANDSAT data.

b. The Test Site Survey

Distances and true directions from test site corner points to reference points were determined by pacing and use of a Silva sighting compass. Normally, several such fixes were obtained at each test site, and test site boundaries were laid out by pacing and use of a sighting compass.

c. Test Site Sampling

In 1973, 11 test sites were visited and data were collected at 397 sample points. A modification of the sampling technique described by Ohmann and Ream (1970) was utilized. The following data were collected at each sample point:

1. Distance to, diameter at breast height, and species of the

nearest live tree in each quadrant about each sample point

2. Distance to, diameter at breast height, and species of the nearest sapling in each quadrant about each sample point. Within the context of this paper, a sapling has a single main trunk, a dbh of less than 6 cm, and is less than 4 m tall, whereas "trees" have a dbh greater than 6 cm and are more than 4 m tall.
3. Distance to, diameter at breast height, and species of the nearest standing dead tree (if any) in each quadrant about each sample point; a standard measurement used in forestry which relates to succession.
4. Percent cover by species and extent of browsing on tall shrubs within a 4 m^2 plot about each sample point. Browsing was estimated as being none, less than one-third, one-third to two-thirds, or more than two-thirds.
5. Percent ground cover and composition in a 1 m^2 quadrat at each sample point. Non-living ground cover such as bare rock, bare soil, and standing water were included. Lichens were recorded as either crustose, foliose, or fruticose. Fungi were recorded as "fungi" whether slime molds or true mushrooms. Algal growth was entered as "algae." Vascular plants were identified as to botanical species according to Hulten (1968) except for _Equisetum_ and grass. Sedges were identified to genus as _Carex_, _Eriophorum_, or other sedge. Moss was listed as moss and taxonomic identification was not attempted.
6. The number of caribou and other animal pellet groups or

droppings, as appropriate, in a 4 m^2 plot about each sample point. A number of pellets having the same apparent size, age, and origin were considered as one pellet group.

All data were keypunched onto IBM cards and analyzed using stepwise linear regression with the number of caribou pellet groups being considered the dependent variable. Those vegetation variables which were least correlated to pellet density were eliminated by this procedure and data were reduced to an analytic format containing the following for each sample point:

1. Presence/absence of trees and saplings in each quadrant about each sample point.
2. Percent cover of Salix, a presence/absence indication of species, and the extent of browsing on Salix.
3. Percent cover of Betula glandulosa and Alnus crispa.
4. Percent ground cover for live wood, litter, sedges, moss, lichens, fruticose lichens, Arctostaphylos rubra, Dryas integrifolia, Vaccinium uliginosum, and Vaccinium vitis-idaea.
5. Presence/absence indication for bare soil, bare rock, fungus, grass, standing water, Carex, Eriophorum, Equisetum, Pedicularis, Petasites, Polygonum, Pyrola, Saussurea, Senecio, Stellaria, Anemone parviflora, Andromeda polifolia, Cassiope tetragona, Chrysanthemum integrifolium, Empetrum nigrum, Hedysarum alpinum, Ledum decumbens, Pinguicula vulgaris, Potentilla fruticosa, Rhododendron lapponicum, Salix reticulata, Tofieldia pusilla, and Zygadenus elegans.
6. Number of pellet groups or droppings, as appropriate, within the 4 m^2 plot for caribou, moose, lemming, ptarmigan, and hare.

In 1974, verification data were collected in six one-square-mile areas. Each area contained 441 sample points. Therefore, data in the format described above exists for a total of 3,043 sample points.

d. Indices of Animal Utilization

Aerial reconnaissance of animal distribution and areas of feeding craters were taken as general indicators of winter range utilization by caribou. However, pellet-group counts are an established cervid census technique which is considered valid (McCain 1948, Neff 1968). This method has also been used as an index to habitat utilization by deer (Brown 1961, Julander 1955, Reynolds 1964, Wallmo 1958, White 1960). Pellet-group counts have also been used as an indicator of range utilization by moose and caribou (Scotter 1970). Therefore, this method was used in ground data collection. Step-wise linear regression analysis was applied to the data to determine relationships between caribou pellet density and vegetation.

II. Application of LANDSAT Data

A. Visual Analysis

Direct visual interpretation of LANDSAT data was attempted with a variety of product formats. Initially, 70 mm film chips were examined to identify suitable cloud-free scenes of test areas. Additional product formats such as single-band positive transparencies, false color composite paper prints, false color composite transparencies (all at scale of 1:1,000,000) and computer compatible digital tapes were ordered on the basis of this preliminary screening process.

If visual examination of single band products indicated that the desired features could be discriminated, maps were prepared by visual interpretation of the positive transparencies. A Zoom Transfer Scope was utilized for these analyses. This instrument has the capability of projecting, enlarging, and optically manipulating distortions in the LANDSAT images. The images were projected onto 1:250,000 scale USGS maps and optically adjusted to register with the map. Feature maps were then prepared either directly on the USGS map or on an overlay.

If visual interpretation of single band products was not possible color additive viewer displays were prepared. In this process, false color composite images were created from single band 70 mm film chips. Film chips were mounted, projected, registered to each other, and then blue, green, and red filters were used to construct a false color image. Normally, band 4 transparencies were projected through a blue filter, band 5 transparencies through a green filter, and band 6 or 7 through a red filter. Filter apertures could be adjusted to emphasize or de-emphasize any given band in the display. These displays were experimentally adjusted for maximum enhancement of desired analytic features such as specific vegetation types.

Visual interpretations of false color composite images were accomplished in the same manner as visual interpretations of single band images. Scale mappings (1:250,000) of features were prepared from false color composite positive transparencies on a Zoom Transfer Scope.

B. Numerical Analyses

1. Discriminant Analysis

Training set data were located and extracted from digital tape format LANDSAT data. These data were then analyzed using Gaussian linear discriminant functions as implemented in an existing biomedical program, PDM-07M. This program assesses the feasibility of discrimination between training sets, lists variables in order of importance or utility in the discrimination, and lists percent accuracy of discrimination using one, two, three, or all four variables. These results immediately determined if discriminations were feasible and, if so, which bands were most useful. This approach was far more efficient than subjective evaluation of all data product formats and provided definitive evaluation as to whether single band analyses were worth attempting, and, if so, which band would produce the best results. Therefore, discriminant analysis became a first step in the analytic efforts.

2. Single band density slicing

Analyses based on single band density slicing were carried out with a VP-8 analyser on the positive transparencies and/or with a CDU-200 on the digital tapes. See Appendix B for description of this equipment and the CDU-200.

3. CDU-200 Format

At this point, it is necessary to discuss the CDU-200 in greater detail. The differences between this equipment and the VP-8 are data input format, cost, and accuracy. The VP-8 provides indication of relative densities, e.g., the densities measured are a function of existing lighting and the particular transparency used. Changes in lighting conditions during or between analyses will invalidate the comparisons of results. Therefore, display results are not precisely reproducible.

The CDU-200, however, sliced absolute densities, i.e., the unchanging density values present on the digital tape. Therefore, results of a slicing with this equipment were always exactly reproducible. The CDU-200 would not accept NASA tapes directly as input with the existing software at the University of Alaska. Instead, a special tape format is required and a reformatted input tape must be generated from the original NASA tape. With existing software and hardware, the maximum informational content of input tapes is a 512 x 512 x 4 matrix or about 2.5 percent of a LANDSAT scene.

4. Multiband linear slicing

Because processing software required CDU-compatible tape format, original NASA tapes could not be processed directly. It was necessary first to produce a tape in CDU-compatible format. Then, target signatures could be determined on the TV monitor one band at a time or from line printer outputs of the CDU tape.

After the target signatures were determined, a feature categorized tape was generated by applying a heuristic algorithm to the CDU-compatible raw data tape. This consisted simply of a statment of density range criteria in two or more bands, e.g., if pixel density is between X and Y in band 4, R and S in band 5, etc., then classify that pixel as feature type A. Obviously the statements of criteria for categories must be mutually exclusive for successful processing. That is, density range statements can never be overlapping such that a given pixel might simultaneously fulfill criteria for more than one category. Because feature target density ranges often to overlap to some extent, it is necessary to "chop tails" from some distributions.

Consider the hypothetical example where target feature A has a range of 12 to 17 in band 5 and target feature B has a range of 17 to 20 in band 5. No other categories in the analysis have band 5 densities between 12 and 20. Assuming that density ranges of A and B overlap more extensively in other bands, it is necessary to limit the ranges in the algorithmic statement such that A and B can be separated. For example, the range of A could be stated as 12 to 16, the range of B could be stated as 18 to 20, or both. In the first case, some A points would be misclassified as being B. In the second case, the reverse is true. In the last case where both distributions are curtailed, all A or B points with a band 5 density of 17 would be left unclassified by the algorithm. Therefore, implementation of this type of algorithm is somewhat flexible and may be tailored to the goals of a specific investigation.

After the raw tape has been processed and a feature-categorized tape generated, the new tape may be used to produce line printer "maps" where each category in the analysis is represented by a printer symbol. Inherent characteristics of the line printer, such as printing 3.9 characters per cm horizontally but only 2.4 lines per cm vertically, result in aspect-ratio distortion of the data. A simple computer program was written to correct this distortion by doing nothing more than generating "dummy" data lines such that an average of only 2.4 real characters per cm is presented horizontally. This procedure results in a fixed scale product which is approximately 1:18,540.

5. Maximum likelihood classification

In addition to the heuristic algorithm described above, there are many different classification algorithms in use for processing remote sensing data. Of these, the most widely used is maximum likelihood based on Gaussian Quadratic discriminant functions. There are many specific methods of implementing the algorithm. The most direct implementation described by Phillips (1974) is perhaps the least cost effective. Alternate, more cost effective methods are discussed by Dye (1974). He described the specific implementation used in this investigation.

After classification was completed, systematic geometric corrections were applied to the data and these corrected data were processed through a high speed film recorder interfaced with the system. Internegatives were produced and used to produce subsequent photographic products. The photographic products produced in this investigation are 1:250,000 scale color coded vegetation type-maps.

6. Verification of map products

Eight points were randomly selected for verification of map products resulting from algorithmic classifications. That is, a random number table was utilized to select eight sets of latitude-longitude coordinates which would serve as the center points for the verification areas. Of these, two points were rejected as being unsuitable from a practical standpoint. One point was located in the Junjik River in an area where the river bed is wide and braided into multiple swiftly flowing channels. Field sampling of this area would have been very difficult and hazardous. The second point rejected was located on the southeast face of Nichenthraw Mountain. Because of the precipitous terrain, field sampling of this area would also have been very difficult, expensive, and hazardous.

The remaining six points were utilized for verification and these areas were visited in the summer of 1974 for collection of vegetation data. Data were collected systematically on a grid approximately 2.56 square kilometers in size. Each grid consisted of 441 sample points located 80 paces apart. The following data were collected at each sample point:

a. The investigator's subjective impression of the vegetation type, e.g., forest (F), Eriophorum tussock community (E), etc., or a type which had not been described in the analysis, unclassified (U).

b. Whether or not there were trees present in every quadrant within 50 meters.

c. Percent cover by species of tall shrubs in a 4 m^2 plot about the sample point.

d. Number of pellet groups in a 4 m^2 plot about the sample point.

e. Percent cover of the five most abundant types or species of ground cover in a 1 m^2 plot.

These data were used to prepare vegetation type maps of each of the areas. These maps were compared with maps produced from satellite data and used as a basis for critical evaluation of maps based on LANDSAT data.

RESULTS

I. Ground Truth

A. Range Utilization Based on Direct Observation

1. 1972

Aerial reconnaissance over extensive areas of northeast Alaska during February and March of 1972 revealed numbers of wintering caribou in the Junjik Valley and the North and East forks of the Chandalar River Valley. Snowcover in these areas was cratered as a result of caribou feeding activity. Neither cratering nor caribou were observed in the Sheenjek, Colleen, Kongakut, or Upper Firth River valleys and the many intervening minor drainages and uplands.

2. 1973

Aerial reconnaissance in the environs of Arctic Village in March revealed caribou utilization of the Junjik Valley, North and East forks of the Chandalar Valley, and the Porcupine Lake basin (Figure 4). These areas were characterized by the presence of wintering animals and extensive cratering. As in 1972, certain areas such as the area near the headwaters of Deadman Creek and the vicinity of Bulb Lake (68°01'N, 145°12'W) were "trackless." There was no indication whatever of any caribou in either winter. This aerial reconnaissance was

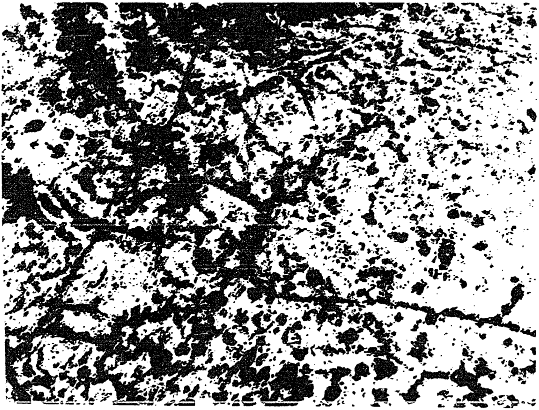


Figure 2. Extent of snowmelt on May 21, 1973, in caribou winter feeding area at 732 m.

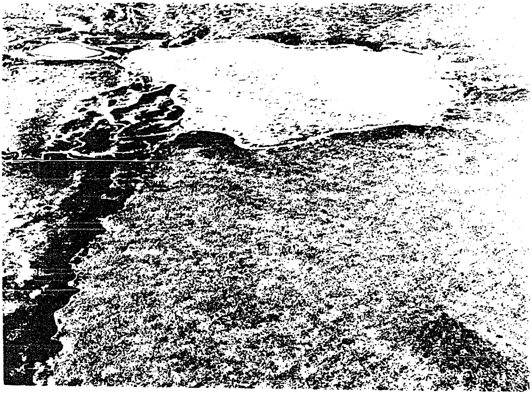


Figure 3. Extent of snowmelt on May 21, 1973, in area not utilized by caribou in winter; elevation 732 m.

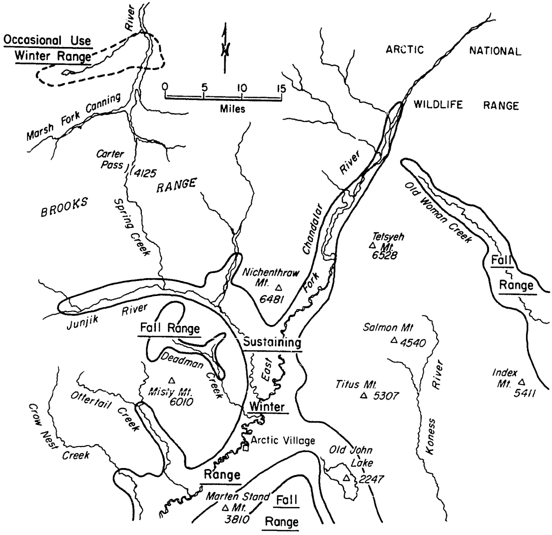


Figure 4. Fall and winter caribou range utilization near Arctic Village, Alaska.

obtained in late March during the period of satellite overpass.

Aerial reconnaissance photography of snowmelt conditions was obtained on May 21, 1973, over all of the above sites except Porcupine Lake. Areas near treeline on the south side of the Junjik Valley illustrate the influence caribou winter feeding has on snowmelt pattern (Figure 2). The circular areas and linear features melted free of snow cover correspond to old feeding crater sites and trails respectively. On the same date, previously unutilized areas at approximately the same elevation had a greater amount of snow which was more uniformly distributed (Figure 3).

B. Range Vegetation

Table 1 lists general vegetation type, caribou pellet group density per ha., and principal flora found at each test site. The terms moderate or low density forest are somewhat misleading. These areas are near northern and altitudinal limits for boreal forest. Consequently, the forest is typically relatively low density, i.e., parklike and the term open lichen woodland is perhaps more descriptive. In order to differentiate between areas which were somewhat sheltered from the wind and other areas subject to windpacking of snowcover, the following criteria were utilized: if in every quadrant there were trees within 50 meters of each sampling point, the area was considered a "moderate" density forest. Areas which have trees but are "very open" were called "low density," i.e., areas where trees were unevenly distributed and at such low density that they would have little wind-sheltering effect. The criterion for these areas was that trees did not occur in every quadrant within 50 meters of sampling points.

Test site locations are presented in Figure 14 and animal utilization data are summarized in Table 1.

C. Range Utilization Based on Pellet Density

Aerial reconnaissance indicated that the Junjik Valley and the North and East forks of the Chandalar River Valley were used by caribou in the winters of 1971-72 and 1972-73. Nearby uplands were used by the animals in the fall (October-November) but in late winter (February-March) these upland areas were trackless, indicating they did not receive use by caribou in mid to late winter. The Porcupine Lake basin area was not used by animals in the winter of 1971-72 but did receive use in the 1972-73 winter (see occasional use area; Figure 4). An unusually large number of caribou from the Porcupine herd was reported to have wintered in Alaska during the 1972-73 winter (R. Le-Resche, Alaska Department of Fish and Game, pers. comm.), but my analysis did not demonstrate a significant difference in the extent of utilization of the Junjik and Chandalar valleys. These areas were extensively cratered during both winters.

Step-wise linear regression analysis of vegetation data in relation to caribou pellet group density revealed a positive relationship between pellet group density and fruticose lichens, other lichens, litter, grass, Chrysanthemum integrifolium, trees, and Polygonum. An inverse or negative relationship was noted for sedges, Salix, Equisetum, Anemone, Senecio, Betula glandulosa, and for droppings of moose, lemming, and hare. The more significant relationships are delineated on Table 3 which is based upon data analysis for 3,043 sample points. The highest pellet

Table 1. Animal utilization of test sites.

Test Site	Location	Elev.	Vegetation Type	Caribou Pellet Density	Other Evidence of Animal Utilization
201 301	N. Fork of Chandalar River Valley	671 m	white spruce forest	.65 1.30	Caribou cratering: 1971-72, 1972-73; several hundred caribou observed in Nov. 1973; remains of 6 hunter-killed animals found on sites in June 1973. Extensive grizzly bear sign on sites.
202 302	N. Fork of Chandalar River Valley	671 m	Low density spruce	.60 .75	Moose observed on sites in June 1973.
203 303	Old John Lake Basin	732 m	White spruce forest	.65 1.05	Remains of several wolf-killed caribou found on site 303; old caribou fence on site 303.
204 304	Junjik River Valley	701 m	White spruce forest	2.65 1.65	Extensive caribou cratering 1971-72 and 1972-73; wintering bands of caribou observed during both winters.
205 305	Junjik River Valley	701 m	Low density spruce	.10 .05	None
206 306	Upland plateau South of Old John L.	823 m	<u>Eriophorum</u> tussock meadow	.35 .50	Some caribou observed in the vicinity in late Nov. 1973
207	Old John Lake Basin	701 m	Low density white spruce	1.20	None
208 308	Porcupine Lake Basin	1037 m	Alpine tundra	2.15 3.90	Extensive caribou cratering, bands of caribou, and wolves observed on the area in March 1973.

Table 1, continued.

Test Site	Location	Elev.	Vegetation Type	Caribou pellet density	Other evidence of animal utilization
209 309	Upland plateau near head-waters of Deadman Creek	945 m	Upland low brush	.65 .55	300 to 500 caribou observed on sites in Nov. 1973
210 310	Lower Sheenjek River Valley	137 m	Recent wildfire burn	0 0	None
211 311	Lower Sheenjek River Valley	137 m	Spruce-poplar forest	0 0	Fox scats found on sites and black bear observed in Sept. 1973

Table 2. Summary of vegetation at test sites.

Test Site #	Classification Type ()=Printout Character	Primary Ground Cover (% Cover)	Principal Tall Shrubs	Principal Tree Species	Major Ecosystem Category*
201	White Spruce Forest (F)	Litter 41.5% *Dryas integrifolia* 28.9% *Carex* sp. 28.8% Moss 27.7% *Cladonia* sp. 16.8% *Vaccinium uliginosum* 12.0% *Arctostaphylos rubra* 6.4%	*Betula glandulosa* *Salix alaxensis* *S. brachycarpa* *S. lanata*	*Picea glauca*/ Moderate density	Upland Spruce-hardwood
301	White Spruce Forest (F)	Litter 32.9% Moss 27.0% *Dryas integrifolia* 17.1% *Carex* sp. 14.4% *Vaccinium uliginosum* 7.2% *Cladonia* sp. 6.7% *Equisetum* sp. 4.8%	*Betula glandulosa* *Salix alaxensis* *S. brachycarpa* *S. lanata*	*Picea glauca* Moderate density	Upland Spruce-hardwood
202	Low density Spruce (O)	Moss 38.7% Litter 24.3% *Carex* sp. 18.2% *Eriophorum* sp. 10.7% *Arctostaphylos rubra* 5.8% *Vaccinium uliginosum* 4.3% *Ledum decumbens* 5.7%	*Betula glandulosa* *Salix arbusculoides* *S. glauca* *S. hastata* *S. lanata* *S. planifolia*	*Picea glauca* Low density	Low Brush

Table 2, continued.

Test Site #	Classification Type ()=Printout Character	Primary Ground Cover (% Cover)
302	Low density spruce (O)	Moss 33% Litter 16.1% *Eriophorum* sp. 13.6% Standing water 8% *Carex* sp. 10% *Dryas integrifolia* 4.4% *Ledum decumbens* 4.0%
203	White spruce Forest (F)	Moss 33.3% Litter 22.5% *Dryas integrifolia* 9.25% *Arctostaphylos rubra* 7.3% *Equisetum* sp. 7.5% *Vaccinium uliginosum* 6.5% *Salix reticulata* 4.6%
303	White spruce forest (F)	Litter 26.8% Moss 22.3% *Dryas integrifolia* 8.8% *Arctostaphylos rubra* 8.8% *Equisetum* sp. 4.4% *Carex* sp. 3.9% *Salix reticulata* 4.6%

Principal Tall Shrubs	Principal Tree Species	Major Ecosystem Category*
Betula glandulosa *Salix planifolia*	*Picea glauca* Low density	Low Brush
Betula glandulosa *Salix glauca* *S. lanata* *S. planifolia*	*Picea glauca* Low density	Upland Spruce-hardwood
Betula glandulosa *Salix arbusculoides* *S. brachycarpa* *S. glauca* *S. lanata* *S. planifolia*	*Picea glauca* Low density	Upland Spruce-hardwood

Table 2, continued.

Test Site #	Classification Type ()=Printout Character	Primary Ground Cover (% Cover)	Principal Tall Shrubs	Principal Tree Species	Major Ecosystem Category*
204	White spruce Forest (F)	Litter 19.0% *Dryas integrifolia* 10.3% Moss 10.2% Fruticose lichen 9.1% *Carex* sp. 7.8% *Vaccinium uliginosum* 6.4% *Arctostaphylos rubra* 5.8%	*Betula glandulosa* *Salix glauca* *S. lanata*	*Picea glauca* Moderate density	Upland Spruce-hardwood
304	White spruce Forest (F)	Litter 20.4% Moss 10.4% *Carex* sp. 8.3% Fruticose lichen 7.1% *Dryas integrifolia* 6.5% *Vaccinium uliginosum* 6.2% *Arctostaphylos rubra* 4.1%	*Betula glandulosa* *Salix glauca* *S. lanata*	*Picea glauca* Moderate density	Upland Spruce-hardwood
205	Low density Spruce (O)	Litter 20.2% Moss 12.6% *Carex* sp. 10.0% Standing water 7.9% *Eriophorum* sp. 6.4% *Arctostaphylos rubra* 4.9% *Dryas integrifolia* 3.8%	*Betula glandulosa* *Salix brachycarpa* *S. lanata*	*Picea glauca* Low density	Low brush

Table 2, continued.

Test Site #	Classification Type ()=Printout Character	Primary Ground Cover (% Cover)	Principal Tall Shrubs	Principal Tree Species	Major Ecosystem Category*
305	Low density Spruce (O)	Litter 22.6% Moss 16.7% *Carex* sp. 12.5% Standing water 6.1% *Dryas integrifolia* 2.7% *Eriophorum* sp. 2.7% *Arctostaphylos rubra* 2.4%	*Betula glandulosa* *Salix brachycarpa* *S. lanata*	*Picea glauca*	Low brush
206	*Eriophorum* Tussock Community (E)	Moss 22.9% Litter 19.5% *Eriophorum vaginatum* 14.8% *Vaccinium uliginosum* 6.7% *Ledum decumbens* 5.8% *Vaccinium vitis-idaea* 5.3% Foliose lichen 5.1%	*Betula glandulosa* *Salix brachycarpa* *S. glauca* *S. planifolia*	None or *Picea glauca* at very low density	Moist Tundra
306	*Eriophorum* Tussock Community (E)	Moss 19.6% *Eriophorum vaginatum* 18.0% Litter 15.9% *Ledum decumbens* 7.8% *Vaccinium uliginosum* 6.9% *Vaccinium vitis-idaea* 6.9% Foliose lichen 5.7%	*Betula glandulosa* *Salix brachycarpa* *S. glauca* *S. planifolia*	None or *Picea glauca* at very low density	Moist Tundra

Table 2, continued.

Test Site #	Classification Type ()=Printout Character	Primary Ground Cover (% Cover)	Principal Tall Shrubs	Principal Tree Species	Major Ecosystem Category*
207	Low density Spruce (O)	Moss 20.3% Litter 19.6% *Dryas integrifolia* 8.3% *Carex* sp. 6.3% Fruticose lichen 5.8% *Vaccinium uliginosum* 4.9% *Arctostaphylos rubra* 7.45%	*Betula glandulosa* *Salix brachycarpa* *S. glauca* *S. lanata*	*Picea glauca* Low density	Low brush
208	Alpine Tundra	Moss 24.6% *Vaccinium vitis-idaea* 13.9% Litter 10.6% Foliose lichen 8.7% Fruticose lichen 7.7% *Ledum decumbens* 6.3% *Cladonia* sp. 13.4%	*Betula glandulosa* *Salix glauca* *S. planifolia*	None	Alpine Tundra
308	Alpine Tundra	Moss 21.5% *Cladonia* sp. 13.7% Litter 10.6% *Vaccinium vitis-idaea* 8.5% Foliose lichen 6.7% Fruticose lichen 6.0% *Ledum decumbens* 3.6%	*Betula glandulosa* *Salix glauca* *S. planifolia*	None	Alpine Tundra

Table 2, continued.

Test Site #	Classification Type ()=Printout Character	Primary Ground Cover (% Cover)	Principal Tall Shrubs	Principal Tree Species	Major Ecosystem Category*
209	Upland Shrub Willow (L)	Litter 23.8% *Dryas integrifolia* 10.3% *Carex* sp. 9.1% Moss 8.6% Fruticose lichen 5.4% *Salix reticulata* 5.2% *Vaccinium uliginosum* 4.4%	*Salix glauca* *Salix lanata* *Betula glandulosa*	None	High brush
309	Upland Shrub Birch (B)	Litter 20.7% Moss 8.5% *Salix reticulata* 5.7% *Carex* sp. 5.7% *Arctostaphylos rubra* 4.9% Fruticose lichen 4.5% *Dryas integrifolia* 7.1%	*Betula glandulosa* *Salix glauca* *S. lanata*	None	High brush
210	Recent Wildfire Burn (B)	Litter 29.4% *Marchantia* sp. 28.25% Moss 22.7% *Epilobium angustifolium* 10.1 *Equisetum* sp. 2.8% *Gramineae* sp. 2.7% Mushrooms 0.75%	*Rosa acicularis* *Salix alaxensis* *S. arbusculoides* *S. glauca*	None but standing dead	---

Table 2, continued.

Test Site #	Classification Type ()=Printout Character	Primary Ground Cover (% Cover)	Primary Tall Shrubs	Primary Tree Species	Major Ecosystem Category
310	Recent Wildfire Burn (B)	Moss 34.5% *Marchantia* sp. 21.8% Litter 18.0% *Epilobium angustifolium* 9.4 *Gramineae* sp. 5.2% *Equisetum* sp. 1.0% *Senecio yukonensis* 1.0%	*Rosa acicularis* *Salix alaxensis* *S. arbusculoides* *S. glauca*	None but standing dead	---
211	Spruce-poplar Forest (F)		*Salix glauca* *S. arbusculoides* *Rosa acicularis* *Betula glandulosa*	*Picea glauca* *Populus balsamifera* *Populus tremuloides* High density	Bottomland Spruce-Poplar Forest
311	Spruce-Poplar Forest (F)		*Betula glandulosa* *Rosa acicularis* *Alnus incana* *Salix glauca* *S. arbusculoides*	*Picea glauca* *Populus balsamifera* *Populus tremuloides* High density	Bottomland Spruce-Poplar Forest
South end of Anvil Lake	Shallow water(s) 1 m or less	Open water	None	None	Lakes
South end of Lake	Shallow water(s) 1 m or less	Open water	None	None	Lakes

Table 2, continued.

Test Site #	Classification Type ()=Printout Character	Primary Ground Cover (% Cover)
Middle of Old John Lake	Deep water (D): 20 m or more	Open water
Gravel bar at confluence of Otter Creek and Junjik R.	Gravel (G)	Bare gravel
Top of Nichenthraw Mt.	Bare rock (K)	Bare rock or scree
Chandalar River	Intermed. depth water (I and/or R): 1 to 5 m	Open water

Principal Tall Shrubs	Principal Tree Species	Major Ecosystem Category*
None	None	Lakes
None	None	Riverine
None	None	Alpine Tundra
None	None	Riverine

Table 2, continued.

Test Site #	Classification Type ()=Printout Character	Primary Ground Cover (% Cover)	Principal Tall Shrubs	Principal Tree Species	Major Ecosystem Category
Large stand of willow adjacent to Water Creek	Willow (W)	Bare gravel	*Salix alaxensis*	None	High brush
Unmelted snowbank on ridge N of Old John L.	Snow (A)	Snow	None emergent	None	Glacier
Clouds of Old John L.	Clouds (C)	---	---	---	---

*Major ecosystems as defined by the Alaska State-Federal Land Use Planning Commission map publications.

Table 3. Vegetation variables related to caribou pellet density in northeast Alaska.

Variable	Sign of Coefficient	RSq	Increase in RSq
Fruticose lichen	(+)	.2107	.2107
Trees	(+)	.2712	.0605
Moss	(-)	.2795	.0083
Salix*	(-)	.2836	.0041
Water	(-)	.2880	.0045
Salix reticulata	(-)	.2930	.0050
Sedges	(-)	.2976	.0046
Salix lanata	(-)	.2992	.0015
Eriophorum	(-)	.3002	.0011
Litter	(+)	.3006	.0003

*Includes *Salix lanata*, *S. brachycarpa*, *S. planifolia*, *S. arbuscu-loides*, *S. glauca*, *S. alaxensis*, and *S. myrtillifolia*.

group densities were found on the alpine tundra sites near Porcupine Lake but indications suggest that this area is not typical winter range and utilization in 1972-73 was a relatively unusual occurrence. For example, all pellets found there showed no evidence of ageing or decomposition. Further, natives from Arctic Village and other persons who have frequented the area for many years said utilization of this area in winter is unusual (A. Thayer, U. S. Fish and Wildlife Service, pers. comm.).

With this exception, pellet densities were highest in relatively open white spruce forest with low density tall shrub understory and a relatively high frequency occurrence of fruticose lichen, grass, *Chrysanthemum integrifolium*, and *Polygonum* in the ground cover. These areas characteristically had low densities of moose, hare, and lemming droppings.

II. Application of LANDSAT Data

A. Map Products Produced by Visual Analysis

1. Snow

Preliminary examination of positive transparencies indicated that snow cover could be distinguished. Therefore, mappings were prepared from two fall scenes, 1063-20271 and 1050-20541, that could be analyzed for snow cover persisting from early season snowfalls. The maps and results in both cases corresponded approximately with topographic contours.

2. Vegetation

Visual discrimination of broad general vegetation types seemed tenable, and vegetation type-mapping of the Arctic Village area was carried out. In this analysis, band 6 positive transparency 1375-21002 dated August 2, 1973, scale 1:1,000,000, was utilized in the Zoom Transfer Scope. Using ground truth test sites as interpretative standards, a feature map was produced by visual interpretation and manual contouring of feature types. A similar analysis of the same scene was carried out using a false color composite transparency.

Visual analyses of portions of scene 1407-20371 were carried out (Figures 5 and 6). In these analyses only three main feature categories were attempted because our ground-truth for the area was very limited. We had surveyed test sites for mature bottomland spruce-poplar forest, recent forest fire burns, and water. Unvegetated gravel was included as an incidental category in the analysis but areas which did not readily identify as forest, burn, or water were left unclassified.

B. Densitometric Classifications

1. Single band

Density slicing analyses for vegetation type were applied to single band transparencies on the VP-8 analyzer. Band 6 was most useful. Results for a portion of scene 1375-21002 near Arctic Village are presented in Figure 7.

2. Multiband density slicing (Heuristic algorithm)

Analysis of scene 1247-20500 for snow cratering areas was attempted. This scene is located north of Arctic Village and dated March 27, 1973. Because visual analyses were not feasible, digital tape data were utilized. Reflectance anomalies were noted on Band 6 which consisted of patches with high reflectance lying on an otherwise

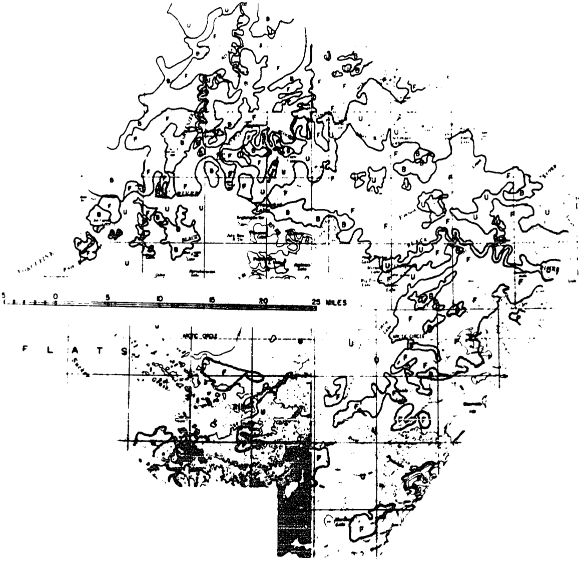


Figure 5. Vegetation map based on visual interpretation of 1:1,000,000 LANDSAT-1 band 7 transparency, scene 1407-20371. Legend: B - recent wildfire burn; F - mature bottomland spruce-poplar forest; U - unclassified.

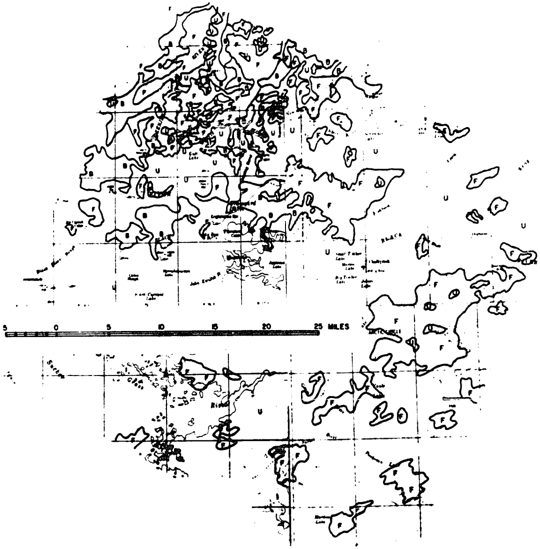


Figure 6. Vegetation map based on visual interpretation of 1:1,000,000 LANDSAT-1 false color composite transparency, scene 1407-20371. Legend: B - recent wildfire burn; F - mature bottomland spruce-poplar forest; U - unclassified.

Figure 7. Vegetation map based on VP-8 analysis of a 1:1,000,000 LANDSAT-1 band 6 transparency, scene 1375-21002.

Legend: 1 - Moderate density white spruce

2 - Low density white spruce

3 - Timberline white spruce

4 - Riparian willow

5 - *Eriophorum* tussock community

6 - Upland brush

7 - *Dryas* community

8 - Alpine tundra

9 - Bare mountain rock

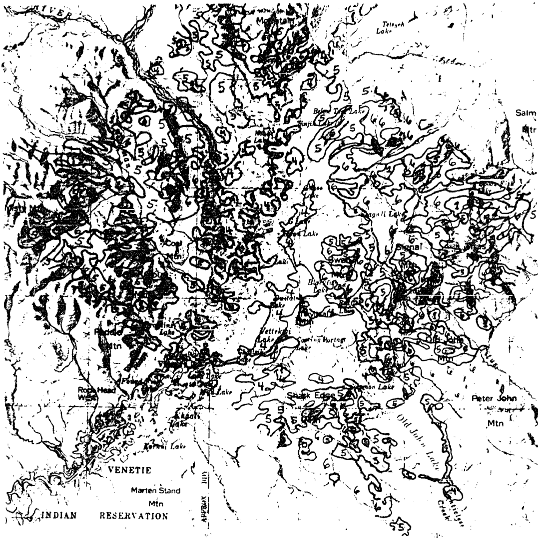

VENETIE
Marten Stand
Mtn
INDIAN RESERVATION
Peter John
Mtn
Old John Lake
Signal
Salm

Figure 7.

open slope and these may or may not have been associated with cratered areas. But, because the cratering sites examined on the ground truth could not be located with confidence on the satellite data, no definite conclusions were possible and the analysis was abandoned.

Discriminant analyses of training set data taken from scene 1407-20371 (September 3, 1974) indicated that bands 5 and 7 were the only significantly useful variables for discriminating forest, burn, gravel, and water. Therefore, only these two bands were utilized in the multiband classification scheme (Table 4). Application of this scheme as a classification algorithm produced tabulated output (Table 5) and a line printer "map" (Figure 9), but the latter was not corrected for aspect-ratio distortion. Therefore, the information was transferred to a 1:63,360 scale map with a Zoom Transfer Scope. The resulting product (Figure 8) was thus optically corrected for aspect-ratio distortion but some detail was lost in the transfer process.

In a similar analysis of scene 1375-21002, discriminant analysis of training set data indicated that all four bands were required to separate all desired target features. Spectral characteristics of desired target features were determined and a multiband classification scheme (Table 6) was devised. Implementation of this scheme as a heuristic algorithm resulted in classification of raw data and production of feature categorized digital tapes. These tapes were used to produce tabular output (Table 7) and line printer maps (Figures 10 and 11) at 1:18,540 scale. Figure 12 illustrates a larger area at reduced scale and delineates the Figure 10 printout area.

Table 4. Linear multiband classification scheme applied to Scene 1407-20371.

Feature	Band 5 Density Range	Band 7 Density Range
Recent Wildfire Burn	12-15	9-11
Mature Bottomland Spruce-Poplar Forest	8-10	5-8
Lakes and Potholes	5-9	0-5
Rivers	10-16	0-4
Unvegetated Gravel	20-32	12-15

Table 5. Linear multiband classification of a portion of scene 1407-20371. (See figures 8 and 9.)

Feature	# of Pixels Classified	% of Total	Area (ha)
Spruce-Poplar Forest	45,420	17.35	22,086
Recent Wildfire Burn	72,445	27.64	35,181
Lakes	8,954	3.42	4,348
Rivers	9,885	3.77	4,800
Unvegetated Alluvial Gravel	1,446	0.55	702
Unclassified	123,934	47.28	60,185
Total	262,144	100.00	127,304

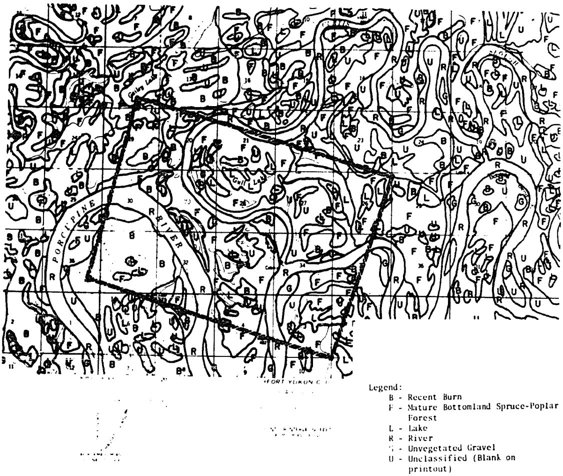


Figure 8. Feature map based on linear multiband slicing of LANDSAT-1 digital MSS data, scene 1407-20371. Area in rectangular boundary is computer printout, Figure 9.

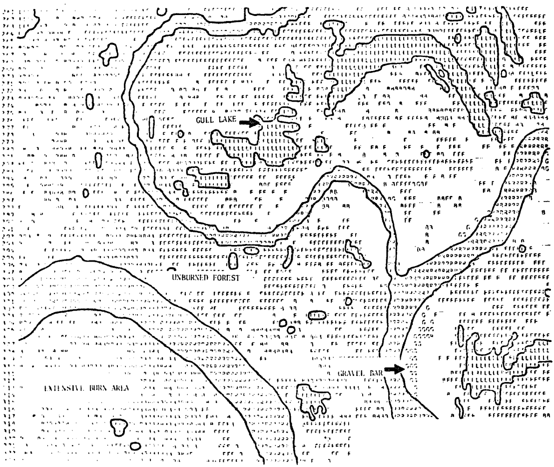


Figure 9. Classified printout of a portion of scene 1407-20371. Reduced ca. 60% and not distortion corrected. See Figure 8 for legend and location.

Table 6. Multiband classification scheme for Scene 1375-21002. (See figures 10-13.)

	Density Ranges			
Features	Band 4	Band 5	Band 6	Band 7
Open Spruce Forest (F)	21-24	14-19	25-28	13-17
Low Density Spruce (O)	19-24	14-19	29-32	12-18
Eriophorum Tussocks (E)	22-23	15-18	30-35	19-20
Upland Shrub community (willow) (L)	17-21	11-16	31-36	19-20
Riparian willow (W)	25-29	20-22	23-30	14-15
Shallow lakes (S)	16-32	20-27	9-18	1-4
Streams (I)	17-20	10-15	9-22	3-8
Rivers (R)	22-27	14-19	10-18	3-7
Deep lakes (D)	16-20	8-11	6-8	0-3
Bare Mountain Rock (K)	22-33	20-29	11-22	5-12
Alluvial Gravel (G)	29-35	25-30	23-29	9-13
Unmelted Snowbanks (A)	20-23	15-20	37-44	21-25
Clouds (C)	27+	22+	36+	21+
Upland Shrub community (Birch) (B)	24-26	11-16	31-36	19-20

Table 7. Linear multiband classification of a portion of scene 1375-21002. (See figures 10-13.)

Printout Character	Feature	# of Pixels Classified	% of Total	Approximate Area (ha)	Caribou Use Index Value
F	White spruce forest	61,258	11.65	29,748	1.33
L/B	Upland brush	21,675	4.11	10,525	.60
O	Low density spruce	68,303	12.99	33,169	.54
E	*Eriophorum* tussock community	41,168	7.82	19,992	.42
D	Deep lake water	5,117	0.96	2,514	Unknown
K,G,S	Bare rock, Gravel, and Shallow water*	36,209	7.20	46,007	Unknown
C	Cloud	22,093	4.18	10,729	---
	Cloud shadow	22,335	4.25	10,846	___
A	Snow	29,274	5.55	14,216	Unknown
W	Riparian willow	5,292	0.97	2,570	Unknown
U	Unclassified	211,506	40.31	102,712	Unknown
	TOTAL	524,288	100.00	254,607	

*In this analysis, interpreter decision was required on final output to separate these features.

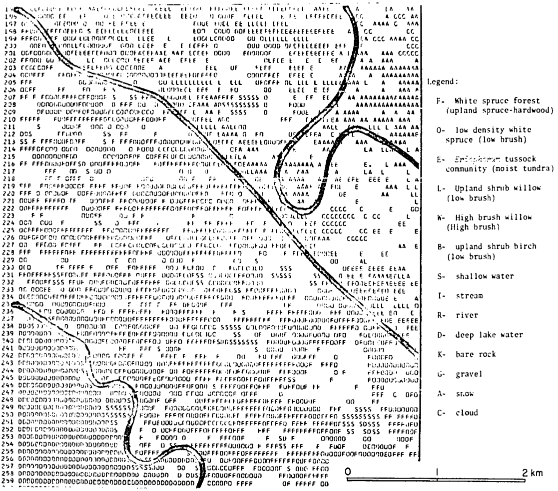


Figure 10. Classified printout showing a portion of habitat map shown in Figure 12. Linear reduction of original ca. 60%.

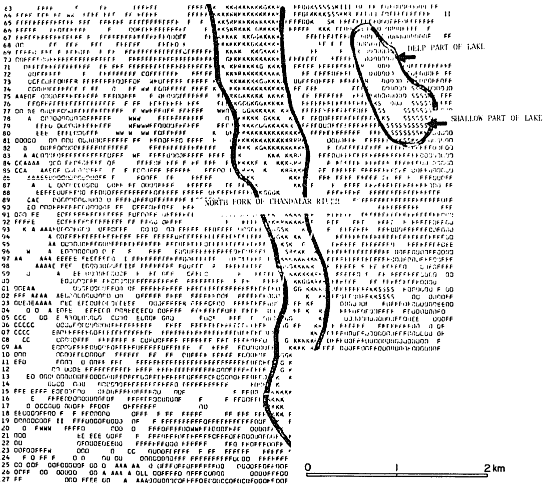


Figure 11. Classified printout of portion of habitat map near Vettatrin Lake (68°30'N, 145°04'W). Linear reduction of original ca. 60%. See Figure 10 for legend.

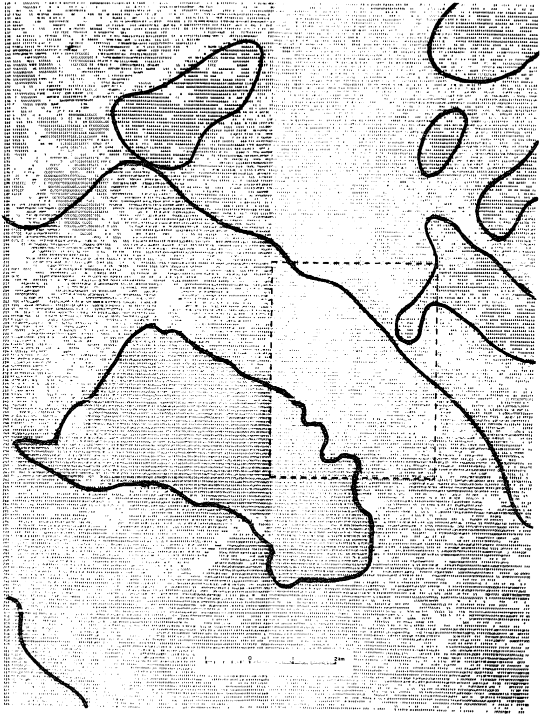


Figure 12. Portion of habitat map based on linear multiband slicing of LANDSAT-1 digital MSS data, scene 1375-21002. See Figure 10 for legend.

C. Map Products Produced by Maximum Likelihood Classification (Gaussian Quadratic Algorithm)

A portion of scene 1375-21002 was analyzed on the Multispectral Data Analysis System (M-DAS) owned and operated by Bendix Aerospace Systems Division. Color coded imagery (Figure 13) at 1:250,000 scale was produced and the color scheme is explained in Table 8. Table 9 indicates the relationship between these categories and type-classes previously used.

D. Verification of Analytic Products

Additional ground truth for verification and evaluation of analytic results was obtained during 1974. Data were collected on six randomly selected areas (Figure 14) with systematic sampling of 440 grid points about the center point of each area. Grid points were 80 paces apart and each area comprised approximately one squarr mile.

Tables 10 through 14 are based on comparisons for 600 point classifications systematically distributed on the six verification areas. Polygon maps based on ground classification of grid points were prepared. Polygon maps based on LANDSAT analyses were also prepared for each area and all verification area maps were enlarged to the same scale. LANDSAT based maps were overlaid on ground based maps and a one hundred point plastic overlay. Figures 15 through 21 are polygon maps of verification Area 1. Figure 15 is based on ground based grid points 80 meters apart. Figures 16 through 20 are based on LANDSAT data interpretations with the various techniques used in the study. Figure 21 is Spetzmann's (1956) classification of the area based on low level aerial photography. Similarly, Figures 22 through

Figure 13. Maximum likelihood classification of scene 1375-21002. Legend:

Dark green - White spruce forest

Light green - Low density white spruce

Dark blue - Shallow water or dark mountain rock

Light blue - Deep water

White - Bare gravel or light colored rock

Tan - Alpine tundra

Turquoise - Sedge meadows

Brown - Fellfields

Yellow - Lichen rich tundra

Red - High brush

Orange and black - Unknown or unclassified

(See Table 7 for greater detail.)

Table 8. Analytic categories produced using interactive cluster techniques and a maximum likelihood classification algorithm.

Category	Description
1	Fell fields - Areas of large diameter (25 cm) dark colored rock sometimes covered with dark crustose lichens; predominantly unvegetated by vascular plants.
2	Alpine tundra - Areas which are principally vegetated but may contain up to 50% exposed rock or soil. Vascular plants may include *Dryas octopetala*, *Carex*, *Empetrum nigrum*, *Arctostaphylos alpina*, *Salix polaris*, *S. arctica*, *Betula nana*, and others.
3	*Eriophorum* tussock community - Areas dominated by tussock forming *Eriophorum*, especially *E. vaginatum*. Other commonly occurring vegetation includes *Sphagnum* moss, *Ledum decumbens*, *Vaccinium uliginosum*, *Vaccinium vitis-idaea*, *Carex*, *Empetrum nigrum*, and *Rubus chamaemorus*. Tall shrubs such as *Salix planifolia* and *Betula glandulosa* are usually present and white or black spruce may be present at low density or entirely absent.
4	Upland *Dryas* community - Ground cover may include *Dryas integrifolia*, moss, litter, fruticose lichen, *Carex*, grass, non-tussock-forming *Eriophorum*, *Empetrum nigrum*, *Arctostaphylos rubra*, and others. Tall shrubs such as *Salix glauca*, *S. lanata*, and *Betula glandulosa* may be present at low density. White spruce may be present in stunted growth form at low density.
5	Alluvial gravel - Principally unvegetated areas of light colored sand and/or gravel. Examples include braided streambed, gravel bars, and lake beaches.
6	Shallow water or mountain outcrop - The classification algorithm was not able to differentiate between shallow water and steep unvegetated shale slopes. The mountain areas consist of dark colored steep slopes of unvegetated rock with many sun shadows. The water is generally less than 10 m deep and underlain by a relatively sterile rock bottom. These two features seem to possess very similar characteristics in the spectral regions available on LANDSAT MSS data.

Table 8, continued.

Category	Description
7	Deep water - Water deeper than about 10 m.
8	Wet sedge meadow - Very wet areas containing an interspersion of water and vegetation. Some examples include low relief pond and lake margins and very wet meadows containing considerable standing water.
9	Wet sedge meadow - Wet sedge meadows; this type is similar to and occurs in association with type 8 but is somewhat drier. The sedges in both types do not form well defined tussocks. Tall shrubs especially Salix planifolia may occur in type 9 but type 8 is too wet for shrub growth. Small "islands" of drier soil may support tree growth in type 9 but these are sporadically distributed and low density.
10	Low density white spruce forest - Principally areas of white spruce with visible ground cover and shrub story. The tall shrub understory consists primarily of Salix lanata, S. brachycarpa, S. glauca, and Betula glandulosa. Ground cover consists predominantly of moss, fruticose lichens, litter, Dryas integrifolia, Arctostaphylos, Carex, grass, Vaccinium, and Empetrum. Some treeless areas at higher elevation are classified to this type but these areas have similar shrub and ground cover.
11	White spruce forest - Areas of moderate density white spruce with a shrub story of Salix and Betula glandulosa. This type is quite similar to type 10 but the trees are higher density and ground cover contains a higher percentage of Equisetum and lower percentage of fruticose lichen.
12	Lichen dominated "tundra" - Areas dominated by ground cover consisting of fruticose lichen, moss, Carex and grass. Depending upon location and elevation, other vegetation such as Arctostaphylos, Vaccinium, Dryas, Empetrum, and others may occur in ground cover. Tall shrubs such as Salix glauca, S. lanata, S. brachycarpa, and Betula glandulosa may be present at low density. White spruce is usually absent but may be present at very low density and stunted growth form.
13	Mixed coniferous-deciduous forest - Areas of moderate density white or black spruce mixed with either Betula papyrifera, Populus balsamifera, and Populus tremuloides.

Table 8, continued.

Category	Description
14	High Brush - Areas dominated by tall shrubs consisting principally of various species of *Alnus* and *Salix*, especially *Salix alaxensis*.
15	Undefined - This type occurs in association with both types 13 and 14 and its occurrence is primarily confined to the southeastern portion of the scene (Yukon Flats) where no detailed ground truth was available.
16	Unknown - This category was reserved for target areas which are unlike all other analytic categories. Examples include clouds, *aufeis*, and any target feature which cannot be classified to one of the above types with 90% confidence (90% projected accuracy).

Table 9. Relation of maximum likelihood categories to previous class designations.

Vegetation Type	Classification Designation	Corresponding Color Number Designation
Spruce Forest I	F	10
Spruce Forest II	O	11
Low Brush	B	9
High Brush	W	14
Alpine Tundra	L	4,12
Moist Tundra	E	3
Exposed Soil-Rock	K,G	2,5
Deep Water	D	7
Shallow Water	S	6

Table 10. Summary results of visual interpretation of Band 6 LANDSAT positive transparency (see Figures 17, 24, 31, 38, 45, and 52).

Vegetation Type	Vegetation Type based on LANDSAT Map													
	Total Percent	Total Omitted	Spruce Forest I	Spruce Forest II	Low Brush	High Brush	Alpine Tundra	Moist Tundra	Exposed soil-rock	Deep water	Shallow water	Other	% Omission Error	% Correct
Spruce Forest I	286	51	234	2		14	4	10			20	1	18	82
Spruce Forest II	58	56	24	2		13	1	5			12	1	96	4
Low Brush	0	0			0								--	-
High Brush	12	12	5	1		0	3	1			1	1	100	0
Alpine Tundra	31	16				12	15	4					52	48
Moist Tundra	83	74				3	70	9				1	89	11
Exposed soil-rock	0	0							0				-	-
Deep water	0	0								0			-	-
Shallow water	52	9	6	3							43		17	83
Other	78	78	28	6		12	16	7			9	0	100	0
Totals	600	296												
Total Indicated			297	14	0	54	109	36	0	0	85	4		
Total Committed			63	12	0	54	94	27	0	0	42	4		
% Commission Error			21	86	0	100	86	75	0	0	49	100		

Table 11. Summary results of VP-8 density slicing analysis of Band 6 LANDSAT positive transparency (see Figures 18, 25, 32, 39, 46, and 53).

Vegetation Type	Vegetation Type based on LANDSAT Map													
	Total Percent	Total Omitted	Spruce Forest I	Spruce Forest II	Low Brush	High Brush	Alpine Tundra	Moist Tundra	Exposed soil-rock	Deep Water	Shallow Water	Other	% Omission Error	% Correct
Spruce Forest I	286	80	206	6			30	35			6	3	28	72
Spruce Forest II	55	53	22	2		3	16	7			4	1	96	4
Low Brush	0	0			0								-	-
High Brush	12	12	3	1		0	8						100	0
Alpine Tundra	31	1					30	1					3	97
Moist Tundra	83	83					83	0					100	0
Exposed soil-rock	0	0							0				-	-
Deep Water	0	0								0			-	-
Shallow Water	52	15	8	3		1	2	1			37		29	71
Other	81	81	32	3			40	6				0	100	0
Totals	600	325												
Total indicated			271	15	0	4	209	50	0	0	0	47		
Total committed			65	13	0	4	179	50	0	0	0	10		
% Commission Error			24	87	0	100	86	100	0	0		21		

Table 12. Summary results of visual interpretation of a false color composite LANDSAT positive transparency (see Figures 19, 26, 33, 40, 47, and 54).

Vegetation Type	Vegetation Type based on LANDSAT map													
	Total Percent	Total Omitted	Spruce Forest I	Spruce Forest II	Low Brush	High Brush	Alpine Tundra	Moist Tundra	Exposed soil-rock	Deep Water	Shallow Water	Other	% Omission Error	% Correct
Spruce Forest I	281	34	247	1			23	4			6		12	88
Spruce Forest II	53	51	27	2			11	6			6	1	96	4
Low Brush	0				-								-	-
High Brush	14	11	5	6		3							79	21
Alpine Tundra	28	24	1	16			4	7					86	14
Moist Tundra	82	82		69			13	0					100	0
Exposed soil-rock	1	1	1						0				100	0
Deep water	-									-			-	-
Shallow Water	51	12	9	3							39		24	76
Other	90	84	38	13			23	3			7	6	93	7
Totals	600	298												
Total indicated			325	110	-	3	74	20	0	-	58	7		
Total committed			81	108		0	70	20	0		19	1		
% Commission Error			25	98		0	95	100	0		33	14		

Table 13. Summary results of simple algorithm (multiband density slicing) processing of LANDSAT digital data (see Figures 20, 27, 34, 41, 48, and 55).

	Vegetation Type based on LANDSAT map													
Vegetation Type	Total Percent	Total Omitted	Spruce Forest I	Spruce Forest II	Low Brush	High Brush	Alpine Tundra	Moist Tundra	Exposed soil-rock	Deep Water	Shallow Water	Other	% Omission error	% Correct
Spruce Forest I	287	173	94	64		1	2	7			2	97	60	40
Spruce Forest II	57	38	5	19		1	2	4			6	20	67	33
Low Brush	0	0											-	-
High Brush	10	10	1	1				1			1	6	100	0
Alpine Tundra	33	28		3			5	8				17	85	15
Moist Tundra	83	56	1	11			5	27				39	67	33
Exposed soil-rock	1	1										1	100	0
Deep Water	0	0											-	-
Shallow Water	55	44	3	3				1		11	11	26	80	20
Other	74	39	11	15			2	8	2		1	33	53	57
Totals	600	389												
Total indicated			115	116	0	2	16	56	2	11	21	239		
Total committed			21	97	0	2	11	29	2	11	10	206		
% Commission Error			18	84	0	100	69	52	100	100	48	86		

Table 14. Summary results of maximum likelihood algorithmic processing of LANDSAT digital data (see Figures 21, 28, 42, 49, and 56).

Vegetation Type	Vegetation Type based on LANDSAT map													
	Total Percent	Total Omitted	Spruce Forest I	Spruce Forest II	Low Brush	High Brush	Alpine Tundra	Moist Tundra	Exposed soil-rock	Deep Water	Shallow Water	Other	% Omission Error	% Correct
Spruce Forest I	285	183	102	38	5	7	30	4	2		14	83	64	36
Spruce Forest II	56	45	10	11	4	2	8	4			1	16	80	20
Low Brush	0	0			0								-	-
High Brush	12	12				0	4	6				2	100	0
Alpine Tundra	31	23	1	12			8	9				1	74	26
Moist Tundra	83	34		4	6	2	11	49				11	41	59
Exposed soil-rock	0	0							0				-	-
Deep Water	0	0								0			-	-
Shallow Water	53	26	8	1			1	3			29	13	49	51
Other	80	33	16	4	1	8	1	1	1	1	1	12	41	59
Totals	600	356												
Total indicated			137	70	15	12	70	76	3	1	45	138		
Total committed			35	59	15	12	62	27	3	1	16	126		
% Commission error			25	84	100	100	89	35	100	100	35	91		

Table 15. Verification data applied to Spetzman's (1956) maps.

Vegetation Type	Vegetation types based on Spetzman's (1956) map.								
	Total Present	Total Omitted	Low Forest	Brush	Tundra	Water	Other	% Omission	% Correct
GROUND TRUTH DATA MAP									
Low Forest (F & O)	341	14	465					04	96
Brush (L, B, & W)	30	30		0				100	0
Tundra (Alpine & Moist)	99	14			135			14	86
Water (S & D)	55	55				0		100	0
Other	75	75					0	100	0
TOTALS	600								
Total indicated			327	0	85	0	0		
Total committed			138	0	50	0	0		
% Commission error			42	0	58	0	0		

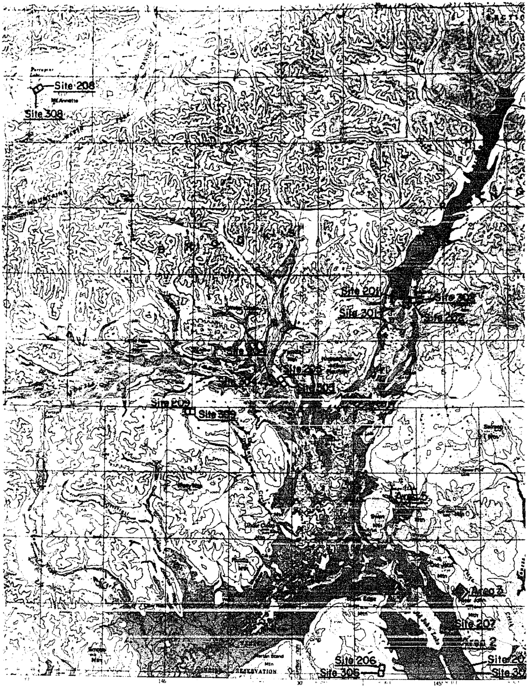


Figure 14. Location of verification areas and test sites.

28, 29 through 35, 36 through 42, 43 through 39, and 50 through 56 are corresponding polygon maps for verification areas 2 to 6 respectively. (See Figure 14 for location of verification areas.) These figures form Appendix C.

DISCUSSION

I. Ground Truth

Based upon aerial reconnaissance observations during the research period, caribou utilized upland areas in the fall and spring and the animals observed in these areas were almost always moving. During the winter, the animals generally utilized forested valley bottom areas, and, while they no doubt moved about within the valleys, they remained in this type of habitat through most of the winters of 1971-72, 1972-73, and 1973-74.

The upland areas consisted of a variety of vegetation types such as *Eriophorum* tussock meadows, wet mat-forming sedge meadows, *Dryas* communities with varying densities of tall shrubs, fell fields, and shrub-dominated communities. Caribou were most often found in sedge meadows during the fall. However, this may or may not be related to grazing preferences. Because these meadows are most abundant at the low points of montane drainages, they coincide with minimum altitude routes between major lowland drainages. Therefore, observations of animals in these vegetation types may have been related to seasonal movements rather than forage preference. Pellet densities found on these areas do not support a hypothesis of extensive utilization.

Lowland areas consisted of a variety of vegetation types such as open lichen woodland, wet sedge meadow, high riparian brush, and bogs. Both reconnaissance observations and pellet density data support a hypothesis of extensive utilization of open lichen woodlands by wintering caribou.

Step-wise linear regression analysis indicated caribou pellet densities were highly correlated to the abundance of fruticose lichens. Pellet group densities also showed positive correlations to Picea glauca, litter, and negative correlations to sedges, moss, Salix lanata, Salix reticulata, Eriophorum, and water, thus suggesting that animals avoid lichen-poor areas, i.e., dense brush, wet meadows, and bogs.

The most important winter range in northeast Alaska is a composite of Spruce Forest I and Spruce Forest II. This composite might more descriptively be called open lichen woodland. Almost all of the Spruce Forest I type may be considered open lichen woodland with the exception of very dense stands where Equisetum dominates the ground cover. Those areas of Spruce Forest II which are reasonably well drained with lichen dominated ground cover also may be considered open lichen woodland. However, many areas of Spruce Forest II which satisfy the technical definition for this type are not open lichen woodland. For example, some areas which are clearly bogs satisfy the arbitrary definition of Spruce Forest II. Therefore, neither of these vegetation types corresponds precisely to optimum caribou winter range.

Much of the major ecosystem type "Upland Spruce-Hardwood Forest" is open lichen woodland. Both Spruce Forest I and Spruce Forest II are primarily subtypes of Upland Spruce-Hardwood Forest. Similarly, spruce forest I and II may be equated to Spetzman's (1956) type Low Forest, which is also a subtype of Upland Spruce-Hardwood Forest.

In summary, none of the types described may be equated with good caribou winter range. Essentially, good caribou winter range in northeast Alaska is defined by areas which have a relative abundance of accessible fruticose lichens in the ground cover. Accessibility is presumably defined by factors such as depth and hardness of the snowpack. In most cases, the presence of relatively open spruce forest exerts a modifying influence on these parameters. The forest is open enough to permit good lichen growth in the ground cover yet the trees act as a windbreak thus preventing windpacking and drifting. If these areas are not subject to extremely heavy snowfalls or high winds they are good caribou winter range.

In northeast Alaska, the most suitable and extensive winter range occurs in forested valley bottoms. Certain areas at high elevation near timberline are forested but, because of their elevation and exposure, they are more subject to high winds resulting in windpacking and drifting. These areas, however, along with treeless uplands which have good lichen growth, are presumed to be excellent winter range in certain years of favorable snow conditions. Consequently, caribou winter range in northeast Alaska consists of two basic types which I propose to be sustaining range and occasional range.

Sustaining range is open lichen woodland found in the valley bottom areas of the major south slope drainages. My suggestion is that these ranges are repeatedly used year after year and sustain wintering animals in even the harshest winters.

Examples of this type of range are the open lichen woodlands of the Junjik and Chandalar valleys (Figure 4). The sustaining range hypothesis is supported by the density and condition of pellet groups occurring on sites in these valleys. These exhibited a continuum of decomposition suggesting a long history of repeated use. Some pellet groups were lichen encrusted and almost entirely overgrown by moss indicating they were quite old. Others showed no evidence of decomposition and were relatively recent. Still other groups had decomposition states intermediate between these extremes.

The other type of caribou winter range in northeast Alaska is occasional use range. These areas are treeless uplands with a relative abundance of fruticose lichen in the ground cover. The standing crop of fruticose lichen on these areas may considerably exceed the standing crop on sustaining ranges. For example, open lichen woodland sites in the Junjik Valley had an average of 14.6 percent fruticose lichen cover. Caribou pellet densities and lichen abundance were both greater in the Junjik Valley than other open lichen woodland sites. However, tundra sites in the Porcupine Lake Basin had an average of 28.4 percent fruticose lichen in the ground cover. This condition may be the result of limited and sporadic utilization of these areas by caribou. In mild winters when the lichens in these areas are presumed to be accessible, such range may receive extensive use. For example, alpine tundra areas in the Porcupine Lake Basin were extensively utilized by caribou in the winter of 1972-73 (Roseneau 1974). The density and condition of pellet groups found on sites in this area support a hypothesis of sporadic or occasional use range. Although pellet group density was relatively high in the summer of 1973, all groups observed in this area showed no evidence of decomposition and were apparently quite recent.

In summary, results indicate fruticose lichens are the most important vegetative factor defining caribou winter range in northeast Alaska, but utilization data suggest that other factors related to the availability of forage determine the patterns of winter range use. Indications are that existing range is of two types, namely, sustaining or repeated use range and occasional or sporadically used range. Presumably, use of occasional range is governed by the occurrence of favorable snow conditions in certain years. Trees are normally present on sustaining range and exert a modifying influence on snow conditions but trees may or may not be present on occasional range.

Although lichens are important winter forage in this part of Alaska, no implication of preference or necessity is intended. For example, there is a meadow entirely devoid of lichens in the Junjik Valley. The vegetational association is unusual and ground cover consists primarily of sedges and Equisetum. It is not a wet sedge meadow, however, nor is it a tussock meadow. The ground is firm and relatively well drained. Both Carex and Eriophorum grow interspersed with relatively short Equisetum. The area almost has the appearance of a cultivated lawn. This meadow has been extensively cratered by caribou every year of this study and caribou have been observed feeding there in winter. Obviously, these animals were not feeding on lichens and, while specific forage could not be determined, it presumably had to be sedges, Equisetum, or both. Because is it atypical, this type of vegetation is not considered important winter range in northeast Alaska.

However, the fact that wintering caribou consistently feed there each year suggests that alternate foods, if available, will be eaten and perhaps even preferred, and some investigators suggest sedge meadows are important late winter ranges (LeResche, Alaska Department of Fish and Game, pers. comm.). This suggestion is supported by Bergerud's (1971) work in Newfoundland where caribou winter primarily on sedge ranges. Generally, however, lichens are the most important winter forage for caribou throughout Alaska and most of the Canadian Northwest (Klein 1970, Skoog 1968, Scotter 1967, Kelsall 1968).

II. Application of LANDSAT Data

A. Range Mapping

Tabular results presented in tables 10 through 14 require further explanation. First, the degree of detail attempted in algorithmic analyses of digital data has never before been attempted. Because detail on resulting map products is much greater, registration problems are severely magnified. For example, note the inconsistencies across tables in the "Total Present" column. Although each map was registered as closely as possible to ground data maps along with the plastic grid point overlay, slight differences in registration resulted in the Spruce Forest I category varying from 281 to 287. If the grid point overlay could have been perfectly registered for each extraction, the same number of points would have been recorded as Spruce Forest I in every table. Therefore, a ± 2 percent error is produced by misregistration for maps as detailed as the ground data maps. The maps produced by visual and VP-8 techniques (Figures 17 through 19, 24 through 26, 31 through 33, 38 through 40, 45 through 47, and 52 through 54) are less detailed than the ground data maps (Figures 16, 23, 30, 37, 44, and 51). Therefore, registration errors in these verifications can be expected to be negligible. However, the maps produced by algorithmic classification of digital data (Figures 20, 21, 27, 28, 34, 35, 41, 42, 48, 49, 55, and 56) are more detailed than the ground data maps. Consequently, slight misregistration can be expected to produce major errors in verification. Other remote sensing investigators (Krumpe, Lauer and Nichols 1973) characteristically use a "cell approach" to verification. That is, they divide the verification area into a number of "cells" and consider the classification correct if most of the cell is classified Type "X" on both maps. This type of verification is much less sensitive to registration errors. It is, however, less defensible statistically than the point verification method used here.

In summary, major errors resulting from misregistration are not significant for tables 10, 11, or 12, but are likely to be significant for tables 13 and 14.

Algorithmic classifications were implemented with the option of classifying areas as "unknown" in terms of established categories. This option could not have been objectively utilized with the other techniques. Definitive decisions were made and areas were assigned to one of a number of specific classes. Therefore, omission errors in tables 10, 11, and 12 imply corresponding commission errors. That is, if 10 points were not correctly classified, they were misclassified. Conversely, omission errors in tables 13 and 14 do not imply corresponding commission errors because these points were often classed "unknown". This is probably due in part to the 90 percent rejection threshold used in the classification. Unless the calculated probability that a pixel belonged to an established class exceeded 90 percent, the maximum likelihood algorithm opted for the "unknown" class. From the standpoint of the verification methods used here, there would be considerable improvement in results by directing the algorithm to a forced choice. The figures in the "percent correct" column would approximately double in most cases.

Because these analysis are more complex than have been attempted previously, the nature of commission errors must be considered. For example, classification of a point to Spruce Forest II when it is actually Spruce Forest I is not as serious an error as classing the same point as Moist Tundra. Examination of tabulated results indicates that combination of similar categories into broader general classes will greatly improve tabulated accuracies in most cases. Spetzman mapped the area from aerial photographs in 1956. He classed four of my six verification areas as being entirely low forest, one as tundra meadows, and one as a combination of tundra meadows and low forest. Overall, his classifications are approximately 75 percent correct with 25 percent commission errors (Table 15).

The grid resolution utilized in ground truth data appears to be too coarse for a fair evaluation of algorithmic techniques and the definitions of vegetation categories present similar problems. That is, these definitions are adequate for evaluation of low resolution techniques based on photographic products (visual interpretation and VP-8 analyses) but are too general to provide a true assessment of high resolution algorithmic classifications based on digital data.

The ground truth verification area maps are based on grid points 80 m apart. These maps are less detailed than the algorithmic classifications. Therefore, it is entirely possible that the algorithmic classifications are more accurate than the ground-truth! This is exemplified at the points shown by arrows on Figures 15 and 20. On the point of land extending into Old John Lake, there is a rocky gravel beach at the headland. This beach is only 20 to 30 m wide and 40 m to 50 m long. In the ground sampling, no sample point occurred on the beach. Sample points falling in the lake were classed as shallow water (S) while inland points on the headland were classed as Spruce Forest II (O). Consequently, a polygon map based on the ground truth grid points does not indicate the presence of this beach. On Figure 20 (see arrow) the beach is detected and correctly classified by the maximum likelihood algorithm. However, according to the ground truth verification on Figure 15 (see arrow), this area is low density forest (O) and the classification on Figure 20 in incorrect. A point falling in this area for verification would be tabulated as an omission error and a commission error. Next, note the area classified as category 12 (lichen rich tundra) behind the beach (Figure 20). This area is a windswept hill with very few small trees irregularly distributed. In many respects, it is very similar to lichen rich tundra. However, according to the arbitrary technical definition used for ground truth, the presence of a single tree within 50 m of the sample point classes that point as Spruce Forest II (O). Therefore, according to ground truth data map (Figure 15), the maximum likelihood algorithm committed a very serious error and classified a forest area as tundra.

Bearing these considerations in mind, tabulated results for each technique will be discussed separately.

1. Visual interpretation of a single band positive transparency (Table 10).

This technique yielded 82 percent correct classification for the Spruce Forest I category and 21 percent commission error. The commission errors were principally misclassification of Spruce Forest II as Spruce Forest I or misclassification of "unknown" (previously undescribed types) areas as Spruce Forest I.

Spruce Forest II classifications were only 4 percent correct with an 86 percent commission error but the commission error involved misclassification of only 12 points.

None of the sample points on verification sites were classed as Low Brush. Therefore, no verification was possible.

Results for the tundra categories are poor unless they are combined. That is, moist tundra was frequently misclassified as alpine tundra and vice versa. If the two are combined to one class, the classification was 86 percent correct with 4 percent commission error.

None of the verification points were exposed soil/rock or deep water.

Shallow water verification points (52) were classified 82 percent correct but an apparent 49 percent commission error involving 42 points occurred. Of these, 9 were aufeis on a lake at Area 1. At the time of verification data collection (mid-June 1974), these points were on aufeis but, on the date of the LANDSAT image (August 2, 1973), this area was probably shallow water. Similarly, other areas of shallow water may have been present in August of 1973, but were no longer so in 1974. Dry lake beds were found in Areas 1, 2, and 6.

In summary, classification of broad general categories such as spruce forest, tundra, etc., is feasible with this technique. Classification accuracies slightly better than those realized by Spetzman (1956) may be anticipated.

2. VP-8 analysis of a single band positive transparency (Table 11)

Simple density slicing of a Band 6 positive transparency resulted in Spruce Forest I classifications 72 percent correct with 24 percent commission error. Spruce Forest II classification was poor with most points (22) erroneously classified as Spruce Forest I.

There were relatively few points of High Brush in the verification and these were principally misclassified as Alpine Tundra.

Alpine Tundra classification was 97 percent correct but commission error was 86 percent. Most of the commission error, however, resulted from Moist Tundra and "unknown" points being misclassified as Alpine Tundra. The "unknown" points are principally unforested wet sedge meadows. Therefore, if these classes were combined to a broad general category such as Spetzman's (1956) "Tundra Meadows," classification accuracy approaches 100 percent with commission error of 27 percent.

Shallow water classification was 71 percent correct with 21 percent commission error but the commission error involved only 10 points.

This technique is essentially a subjective visual analysis. Therefore, it has the same potential applications and accuracy but the advantage is that the interpretative decision need only be made once instead of in every case.

3. Visual interpretation of a false color composite transparency (Table 12).

Spruce Forest I points were classified 88 percent correct with 25 percent commission error. Principal commission error consisted of Spruce Forest II points misclassed to Spruce Forest I. Combination of these classes increases classification accuracy above 90 percent and reduces commission error to 17 percent.

The small number of verification points in the High Brush category (14) precludes any significant evaluation. Three of the 14 were correctly classified and no points were erroneously classed as High Brush (21 percent correct; 0 percent commission error).

Results for tundra categories were poor and, as is evident from Table 12, these points were most frequently misidentified as Spruce Forest II.

Shallow water classification was 76 percent accurate with 33 percent commission error but a substantial number of the commission points probably were shallow water in August of 1973.

This technique produced reasonably good results for forest classes but poor results for the tundra classes. However, the technique depends principally upon the skill and color discrimination ability of the interpreter. Clearly, the composite images contain more information than single band products. Therefore, it follows that a skilled interpreter could achieve at least equivalent results analyzing a false color composite as compared to a single band product.

4. Multiband slicing of digital data (Table 13)

Slicing criteria for this analysis are presented in Table 5 and verification results in Table 13.

Classification accuracy for Spruce Forest I was 40 percent with 18 percent commission error. However, a substantial number (97) of points were classed to "unknown." Therefore, changes in the algorithmic threshold could, in theory, have increased classification accuracy to 67 percent without corresponding increases of commission error.

Spruce Forest II classification was only 33 percent correct with 84 percent commission error. Principally, omissions were assignments to the "unknown" class and commissions were classification of Spruce Forest I as Spruce Forest II. The ground truth definitions are too general for a critical evaluation. Analytic results clearly indicate a capability to discriminate feature classes related to tree density but definition of ground truth classes are too unrefined to evaluate this capability. In particular, the Spruce Forest II ground truth class is highly variable. According to the ground truth definition, timberline points with low tree density but relatively uniform distribution would satisfy the definition. Pond or lake margins in densely forested areas would satisfy the definition. Marshy areas with sporadically distributed "islands" of trees would also satisfy the definition. It has been demonstrated (Krumpe, Lauer, and Nichols 1973) that tree density classes are differentiable with digital image processing techniques to the extent that acreages can be assigned to board footage classes with accuracies upwards of 70 percent. Consequently, the poor results indicated here are most reasonably interpreted as a failure of ground truth technique rather than low analytic power of digital image processing technique. Tabulated results clearly indicate that the digital techniques cannot be used successfully to discriminate between the ground truth classes defined but also indicate that considerably better results could be obtained with more precisely defined ground truth classes.

The low occurrence of High Brush in verification data precludes definitive conclusions. Of a total 10 verification points, 6 were classed "unknown" while the remaining 4 were misclassified as Spruce Forest I, Spruce Forest II, Moist Tundra, and shallow water. Slight misregistration of the verification data could account for the misclassifications.

Alpine tundra classification was only 15 percent correct with 69 percent commission error. More than 50 percent of the points, however, were assigned to the "unknown" class. Correct classifications of these points using altered thresholds would increase accuracy to 67 percent. The high commission error (69 percent) actually involved a small number of points (11) and 5 of these were Moist Tundra.

Classification for Moist Tundra was only 33 percent correct but 39 points were assigned to the "unknown" class. Correct classification of these points with altered thresholds would increase classification accuracy to 80 percent. Commission errors were 52 percent involving 29 points. Of these, 16 Alpine Tundra and wet sedge meadow points were classified to Moist Tundra.

Shallow water classification was only 20 percent accurate but 47 percent of the verification points were classed "unknown" and an additional 20 percent were classed as Deep Water. Commission error was 48 percent but involved only 10 points and is probably the result of misregistration. No depth measurements were taken, but the points classed as Deep Water probably were correctly classified. The 47 percent of points classed as unknown probably correspond to intermediate water depths.

Results of this analysis were generally poor. This occurred primarily because ground truth verification techniques were not suitably matched to the digital data processing technique. Ground truth classes were too broadly defined and input data for signature definition did not include all the variability inherent in the broadly defined classes. In order to use this technique successfully for "simple tasks," all the variability in the class must be sampled and used in signature definition. For example, classification of "Upland Spruce-Hardwood Forest" would require training set data encompassing all the variability inherent to the general definition of this class. That is, the "class" is really a synthesis of multiple classes differentiable with digital data processing technique. These multiple classes correspond to tree density classes, topography, soil moisture, different tree species mixtures, and a number of other parameters. Unless all these "classes" are sampled and utilized in the signature definition, analytic results will not be complete. Therefore, application of these techniques to simple discriminatory tasks is not cost effective because satisfactory results can be achieved with simpler less powerful techniques such as visual interpretation of LANDSAT images.

5. Maximum Likelihood Classification (Table 14)

This technique is similar to the multiband slicing described above in that it involves digital data processing but it is more powerful and more mathematically defensible. Many of the same comments offered above, however, also apply here. The technique does not readily lend itself to simple task applications unless extensive ground truth is available because each broadly defined feature class is actually a synthesis of multiple distinct subcases which can consistently be discriminated with this data processing technique.

As with multiband slicing, the results are generally poor for the same reasons given above. Similarly, the same conclusions apply: dedicated application of this technique to simple single theme feature analyses is not cost-effective except in special classes when extensive ground truth and an interactive mode analytic facility is available.

6. Evaluative Summary of Analytic Techniques

The analytic techniques employed may logically be divided into distinct groups of roughly equivalent analytic power. The first of these is low resolution techniques comprising visual interpretative methods and single band density slicing. Findings indicate these techniques may be used for feature analyses to broad general vegetation categories. Accuracy of results is comparable to analytic results based on conventional photogrammetric techniques (Table 14). The use of LANDSAT imagery, however, is exceptionally cost-effective in comparison because coverage of large areas is available at nominal cost and much less interpreter time is involved in the analysis. The extensive areal coverage of a single LANDSAT image is a distinct advantage. Similar coverage by aerial photography would involve a great number of photos taken on different dates at different light levels and developed with differing degrees of tonal shade for the same target features. Therefore, the interpreter effort required for analysis of a LANDSAT image is much less than would be required for analysis of the same area with airphotos. For example, even with high level

(60,000-65,000 feet) U-2 photography, 25 or more photos would be required for complete coverage of a LANDSAT image. The more conventional aerial photography used in Spetzman's (1956) analysis, however, was much lower level (1500 m) and coverage of a LANDSAT image area would require about 100 photographs.

Algorithmic processing of digital multispectral scanner data forms a second group of techniques. These represent a quantum jump in analytic power but can be difficult and expensive to apply to relatively simple feature analyses. However, this major innovation in remote sensing may soon have wide application in renewable resource technology.

As an example, consider the maximum likelihood classification results presented here. Unlike the other analyses, this analysis was not based on ground truth test site types. Instead, a technique which may be descriptively termed "interactive cluster analysis" was utilized. Training sets were extracted intuitively from LANDSAT data and were accepted or rejected only on the basis of spectral consistency. Ground truth data were utilized after the fact to interpret and define resultant spectral categories. This method is analogous to vegetation mapping techniques employed by Kuchler (1967).

Because of this empirical approach, categories emerging from the analysis may or may not correspond to a priori notions of what should result such as a category corresponding to Upland Spruce-Hardwood Forest or Alpine Tundra. It is evident from the results that this did not, in fact, occur.

However, in terms of specific ecological application, three categories resulting in the analysis represent caribou winter range. Categories 10 and 11 (green on Figure 13) are primarily "sustaining winter range," i.e., open lichen woodland occurring in valley bottom areas of major drainages. The differences between these two classes are: Class 11 has a greater density of tall shrubs and slightly greater tree density; class 10 has lower tree density, lower tall shrub density, and a greater percentage of visible ground cover dominated by fruticose lichens, moss, and litter.

Spectral class 12 (yellow on Figure 13) defines occasional winter range. It corresponds to an abundance of fruticose lichen in the ground cover and is apparently based on a signature for fruticose lichen dominance. These areas are, snow conditions permitting, suitable caribou winter range and correspond to occasional use range as described earlier. This type, however, occurs at a variety of locations and elevations. Therefore, fruticose lichens are important in more than one major vegetation type and these analytic types cannot be readily accommodated to traditional systems of vegetation classification because other factors are also taken into account but perhaps this is why it is a better measure of winter range than analyses which consider only vegetation.

For example, areas in the vicinity of Porcupine Lake which classed to category 12 are clearly Alpine Tundra. Other areas at lower elevation classifying to this type were treeless but the presence of low density tall shrubs precludes use of the term Alpine Tundra. In terms of major ecosystem classification types, these areas might be called Low Brush. Finally, the occurrence of this class in certain valley bottom areas where trees are present at very low density precludes use of either Alpine Tundra or Low Brush. In spite of this failure to fit commonly used classification schemes, areas classed to category 12 have a vegetational common denominator, namely, a predominance of fruticose lichen inthe ground cover. In terms of caribou winter range, this class corresponds to potential high quality range where utilization occurs when snow conditions are favorable.

In summary, these results do not conform to conventional concepts for major ecosystem classification, yet the spectral classes emerging from the analysis have specific ecological significance. In a sense, perhaps these classes have more relevance to caribou biology than major ecosystem types.

7. Recommended Research and Applications

It is evident that a considerable amount of empirical research will be required to perfect operational applications of these techniques. Ideally, this research should generate information which is useful in terms of current needs, provide an analytic data base for more complex future needs, and probe the ultimate informational limitations of multispectral scanner data. The following proposed research approach may be especially appropriate for Alaskan application where ground truth is severely limited and ground truth data collection is relatively expensive.

Cluster analysis can be applied to LANDSAT data to generate spectrally consistent data classes (Wacker and Landgrebe 1972). The number of classes desired can be specified and, without knowing the limitations imposed by meaningful informational content of the LANDSAT data, it is not possible to make an easily defensible statement regarding the number of classes which should be generated. However, the number suggested here is twenty to thirty classes for an initial empirical and pragmatic analysis.

Using the cluster-classes as a training set basis for algorithmic classification, the LANDSAT data can be calssified to produce a feature-categorized digital tape. From this digital tape, line printer feature-class maps can be produced at low cost. The resulting feature-class maps can be used for ground truth data collection. Each class can be extensively sampled and defined.

Evaluation of each feature-class in terms of specific thematic significance will permit a variety of thematic applications. For example, evaluation of each feature-class in terms of timber value would permit formulation of a synthetic analysis for timber resources. Feature-classes of the initial analysis would comprise subclasses of thematic timber value classes. Timber resource maps could then be produced from the feature-categorized digital tapes at a nominal cost. Many other thematic applications such as land-use maps, wildlife habitat maps, etc., may be possible. These applications justify such an analysis in terms of current resource analysis objectives.

The availability of such detailed categorical data may stimulate the evolution of more complex analytic objectives. For example, more detailed ecosystem analyses may be possible over large areas. Refined analyses for specific wildlife habitat can be carried out with software development. As an example of one possible approach, consider a habitat analysis based on mixtures of feature classes contained within blocks of defined size. Suppose the occurrence of feature types A, B, and C in roughly equivalent proportions within a 20 pixel block constitutes ideal habitat for wildlife species X. Software could be written to identify all such blocks occurring on the existing digital tape and a map of this ideal habitat produced. This hypothetical example is only one of the many potential future thematic analyses which may be applied to the basic data resulting from the research approach proposed here.

Finally, this approach is perhaps the most efficient for Alaskan use. Ground truth is not required initially for data classification and field operations are minimized by direct sampling of feature classes already mapped. Because field operations are the most significant analytic cost in Alaska, this approach should be the most cost effective for Alaskan applications. Additionally, this approach does not require interactive mode processing. Therefore, it can be implemented with software on most general computers and is much less expensive than analyses requiring the use of specialized interactive systems.

STATE OF THE ART

Rapid development is occurring in the field of digital image processing primarily in response to the availability of multispectral scanner data in digital tape format. There seem to be two fundamental philosophies or schools of thought in this development, namely, hardware oriented and software oriented.

Both approached often utilize interactive systems which permit the feature analyst to interact with the system during the course of the analysis. Analytic progress is monitored on a visual display console and the analyst trains, classifies small portions of the scene, and continues to manipulate the data until satisfied with the results. Normally, the portion of a scene classified is a 512 x 512 matrix or less. The reason for this is that most large color televisions are limited to this resolution. Therefore, most interactive systems cannot display at full resolution more than approximately 1/32nd of a LANDSAT scene.

1. Hardware-oriented interactive systems

These interactive systems are designed to be self contained or independent of larger general computers. They are normally built around small relatively inexpensive computers such as the PDP-11.

Discs are added to increase memory capacity and special hardware is developed to perform the algorithmic calculations. The advantages of these systems are the interactive capability and the high speed of algorithmic classification. The principal disadvantage of these systems is their relative inflexibility. Normally, they are confined to high speed processing using a particular algorithm. They can be programmed to some extent but this will destroy the advantage of high speed processing. These systems were designed to do specific processing tasks at extremely high speeds and they are specialized operational systems.

2. Software-oriented interactive systems

These systems rely on software implementation of algorithmic processing functions. They are built around small computers or even mini-computers interfaced with larger general computers. Data manipulation and display are carried out on the interactive portion of the system while algorithmic processing calculations are performed by the larger computer.

The most widely used and generally accepted classification method has been the maximum likelihood algorithm based on Gaussian quadratic discriminant functions. Because of the tremendous amount of calculations required by this algorithm, software implementation of this algorithm dictated much slower processing speeds than were possible with specialized hardware. This is, however, no longer true. Several years ago, an algorithmic technique called "table look-up" was introduced (Eppler, Helmke, and Evans 1971). Software developments and revised implementation of this technique have destroyed the advantage of the specialized hardware systems. It has been reported that "classification results from the improved table look-up are identical with those produced by the conventional method, i.e., by calculation of the maximum likelihood decision rule at the moment of classification" (Jones 1974). Moreover, "an entire ERTS MSS frame can be classified into 24 classes in 1.3 hours, compared to 22.5 hours required by the conventional method" (Jones 1974). Other implementations of the method claim even faster processing. "An initial FORTRAN version of this system can classify an ERTS computer-compatible tape into 24 classes in less than 15 minutes" (Eppler 1974). This implies that an entire LANDSAT scene can be processed to 24 classes in less than one hour. This new version of table look-up "requires significantly less core memory, and retains full precision of the input data. The new version can be used on low-cost minicomputers having 32 K words (16 bits each) of core memory and fixed point arithmetic; no special purpose hardware is required" (Eppler 1974).

These developments have, in my opinion, made specialized hardware systems obsolete for all practical purposes. Software oriented interactive systems are cheaper, more flexible, and, because of these developments, currently faster. In light of past development and current rapid progress, the purchase of any specialized system for processing of multi-channel data seems ill advised at this time. However, limited interactive capability for efficient training data extraction is highly desirable and the expense required to develop such capability is quite defensible.

3. Research needs

A great deal of research and development has occurred and is occurring on software development, algorithmic processing techniques, hardware development, and other technical and/or theoretical aspects of machine processing multispectral data. Research papers on these subjects fill the volumes of many symposia, but empirical research correlating theory to application have been sorely neglected.

The myriad spectral classes or discriminations possible with these techniques have not been fully explored. Essentially, the questions "what is being measured?" and "what are the inherent informational content limitations?" have not been satisfactorily answered. The first of these questions is too often inadequately answered "spectral reflectance." However, the physical reality corresponding to these four dimensional spectral classes is yet to be precisely defined. Similarly, the informational limitations inherent to the data have not been adequately defined. While some research of this nature has been carried out, the volume of this type of empirical research has been relatively small compared to theoretical and applications oriented research.

Applications-oriented research addressing a specific theme in terms of current needs or utility is, in a sense, empirical but too narrowly goal-oriented to provide satisfactory answers to the above questions. An a priori answer is provided to "What is being measured?" In forestry applications, timber volume is being measured. In agricultural applications, crop type and expected harvest are being measured. Measurement of these parameters requires synthesis of many spectral classes and such synthesis results in degradation of the informational content of the data.

The cluster analysis method proposed earlier may satisfy proponents of applications-oriented research and concurrently meet some empirical research needs. This technique involves four distinct phases: cluster analysis applied to a randomly sampled 2% of the raw data, algorithmic classification of data using cluster classes as training sets, ground truth definition of classes, and categorical synthesis for thematic analyses.

This method will permit basic research addressing a specific theme such as classification of caribou or moose habitat. At the same time, however, results which are relevant to other themes will be generated and remain available for these applications. Finally, this technique will probe the inherent limitations of satellite multichannel scanner data.

CONCLUSIONS

I. Caribou Winter Range in Northeast Alaska

Findings indicated that the most important wintering areas for caribou in northeast Alaska are forested fruticose lichen range. These forests are principally white spruce at relatively low density. The shrub story consists primarily of *Salix lanata*, *S. brachycarpa*, *S. glauca*, and *Betula glandulosa* at relatively low shrub density. Ground cover is characterized by a relative abundance of fruticose lichens, moss, and *Dryas integrifolia*. This botanical association is a subtype of the major ecosystem type Upland Spruce-Hardwood Forest and occurs at the northern and/or altitudinal limits of its distribution. This range is considered sustaining winter range where lichen forage is available even in severe winters. These areas are vital habitat critical to the survival of wintering populations.

A second type of winter range considered occasional use range is also present. These areas have an abundance of fruticose lichen in the ground cover but presumably forage is not readily accessible except in certain years when snow conditions are favorable. These ranges supplement sustaining range and reduce grazing pressure on sustaining range during favorable years. The availability and utilization of the ranges in any given year, however, cannot be easily predicted. These ranges are considered important but less vital than sustaining range.

Other types of range such as sedge meadows are sometimes utilized in winter but appear to be much less important in terms of their distribution and availability to foraging animals. However, at other times of year, these areas are used by caribou.

II. Potential applications of LANDSAT data to caribou management

1. Habitat analyses

Conventional photogrammetric techniques may be applied to LANDSAT imagery to map the open lichen woodlands described above. Results equivalent or superior to previous classifications based on conventional techniques (Spetzman 1956) can be realized at much lower cost.

Another suggested application is an analysis for burns at the end of each fire season. Recent burns can be mapped easily and quickly over large areas using LANDSAT photographic products. Such a burn analysis could be performed annually throughout all of Alaska at a very nominal cost. In addition to the obvious application of such results to caribou habitat analyses, these products would also have related applications to moose habitat, forestry, and long term studies of secondary ecological succession.

Digital image processing techniques represent a quantum jump of analytic power over conventional photogrammetric techniques. These techniques are, however, extremely sensitive and easily misused. In spite of this, it is evident that highly detailed ecological type maps of large areas are possible using these techniques. Because of the computer compatible format of the digital data, many alternate approaches to habitat analyses are now possible. More empirical research relating ground features to spectral classes is needed, and this research will simultaneously fulfill a variety of application needs including caribou habitat analyses.

III. Remote sensing research and equipment needs in Alaska

Alaska currently provides unique opportunities for remote sensing research and applications particularly in the field of ecology. Because large relatively undisturbed areas exist in a state of seral climax, synoptic scale investigations of geobotanical climatic associations are possible with remote sensing techniques. Further, the high cost of access throughout most of Alaska makes the use of remote sensing for resource inventories highly cost effective. Therefore, expenditures on remote sensing are more justified in Alaska than in any other state.

Two items currently top the priority list of equipment needs:

1. An operational interactive digital image manipulation system which can be used for efficient training set data extraction.

2. An efficient software package for algorithmic processing of digital data on a general computer located in Alaska.

3. Finally, a ground truth scheme to produce verification data of commensurate resolution with analytic methods is needed.

Appendix A.

GLOSSARY OF TERMS AND ACRONYMS

Algorithm: A particular mathematical operation or series of operations automatically applied to data being processed.

CCT: Computer compatible tape, i.e., MSS data in a computer compatible digital tape format.

Commission error: Classification error resulting from misclassification, e.g., a tundra point classified as forest is a forest commission error (see also Omission error).

CDU-200: Analytic equipment marketed by Interpretation Systems, Inc. of Lawrence, Kansas. It consists of a PDP-11 computer, tape drive, added disc memory, telewriter input/output, and a color TV console for data display.

DCS: Data Collection System associated with LANDSAT-1 (ERTS-1).

Dedicated system: A system which is "dedicated" to sole use of a particular operational objective during a specific time period.

Density slicing: Display of a discrete portion of the density range on an image or a digital tape. For example, the technique is used to "slice" the density ranges corresponding to tumors on an x-ray. All such density ranges on the image can then be displayed in a bright color and the high contrast permits detection of even very small areas.

EDC: Eros Data Center, NASA's "retail outlet" for sale of satellite data to the public. It is located at Sioux Falls, South Dakota.

Eigenvalue: A term which refers to individual values of datum in an algebraic matrix.

ERTS-1: Earth Resources Technology Satellite I, launched by NASA in July 1972. It was designed as the first of the EROS (Earth Resource Observation Satellites) series. The name has recently been changed to LANDSAT-1 because terrestrial applications far exceed oceanographic applications.

False color composite: A composite image consisting of several bands of data. These are usually projected through blue, green, and red filters, thus providing color contrast which may enhance specific informational contributions of particular bands. The color filters do not correspond to the spectral regions of the bands, hence the term false color. For example, band 4 (green light) is usually projected through a blue filter, band 5 (red light) is projected through a green filter, and band 6 or 7 (near infrared) is projected through a red filter. Therefore, the resulting colors are false and, in such a composite, vegetation appears red.

Ground truth: In relation to satellite observations, ground-truth may consist of aircraft observations and actual ground observations. These are used for interpretation and verification of interpretation of satellite data.

Hardware: Refers to electronic circuitry, mechanical devices, etc., as opposed to software or computer programs. For example, a simple analog computer is the purest type of hardware system.

Heuristic algorithm: In remote sensing, a simple linear multiband density slicing algorithm and only that type of algorithm.

Interactive system: A computer system having the capability for human analyst "interaction" during data processing. In remote sensing, these systems normally have one or more television consoles for data display at the operator location, controls for data display and extraction, a teletype for operator input, and a line printer for system output. The operator participates in "training" the system to "recognize" desired target features. He may view interim results of the system's classification, call up statistics on training data, "re-train" and, in general, continue to interact in the analysis until satisfied with the results.

LANDSAT-1: See ERTS-1.

Maximum likelihood: A classification algorithm based on Gaussian quadratic discriminant functions.

M-DAS: Multispectral Data Analysis System developed and marketed by Bendix Aerospace Systems Division of Ann Arbor, Michigan.

MSS: Multispectral Scanner System.

NASA: National Aeronautics and Space Administration.

NDPF: NASA Data Processing Facility located at Greenbelt, Maryland.

Omission error: An error where a point is not correctly classified, e.g., a forest point which is left unclassified or is misclassified is a forest class omission error.

RBV: Return Beam Vidicon system.

Software: Computer programs; a "software package" consists of a series of "software routines" collectively designed to meet a certain processing objective on a particular machine.

STDN: NASA's Space Tracking and Data Network.

Table look-up: An algorithmic routine which produces classification results identical to maximum likelihood but with much less actual calculation.

Training set: A group of data associated with a particular analytic target feature. It is isolated and identified to the computer as being typically representative of that feature. This "trains" the computer to "recognize" the feature.

VP-8 Analyzer: A piece of analytic equipment marketed by Interpretation Systems, Inc. It consists of a light table, TV camera, electronic console, and television monitors. It is used for density slicing analyses of black and white photographic transparencies.

Appendix B.

DENSITY SLICING EQUIPMENT

The VP-8 analyzer consists of a light table, camera, television monitor, and control console. Using adjustable crosshairs, relative photographic densities can be determined for any target point on the image. After determining the relative density range of the desired target, the image is "sliced" for display. That is, all densities in that range are displayed as a particular color on the TV monitor.

Similar single band density slicing was accomplished on the CDU-200. This equipment consists of a teletype, tape drive, computer, control console, and TV monitor. Densities for target features are determined and "slices" may be displayed as different colors on the TV monitor.

Hardcopy of results with both the VP-8 and CDU-200 is obtained by photographing the displays. These photo products may then be processed to positive transparencies and display information may be transferred to a scale map by using a Zoom Transfer Scope. These techniques were used to produce feature maps.

Appendix C.

VERIFICATION FIGURES

Figure 15. Ground truth classification of Area 1 based on 80 m grid sample points.

Legend: F - White spruce forest

O - Low density white spruce

E - Eriophorum tussocks

L - Upland shrub; willow

B - Upland shrub: birch

W - High brush

S - Shallow water

D - Deep water

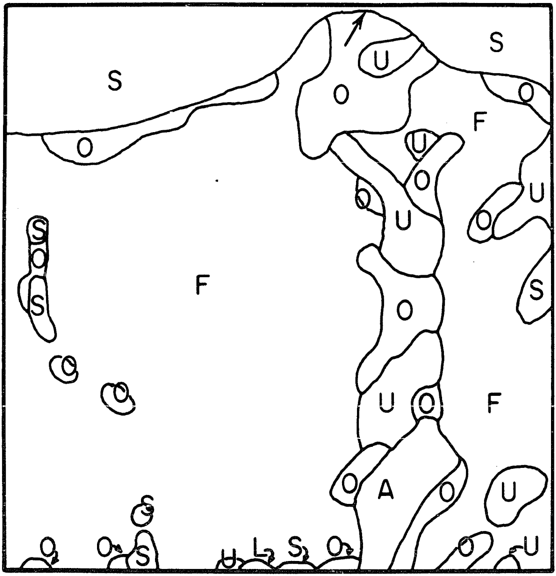
R - River

K - Dark mountain rock

G - gravel

A - Unmelted snow and/or ice

U - Undefined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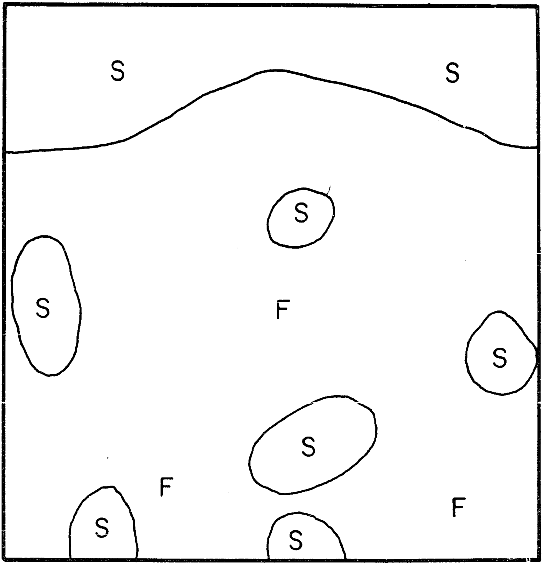


Figure 16. Classification of Area 1 by visual interpretation of a LANDSAT 1:1,000,000 scale band 6 positive transparency. See Figure 15 for legend.

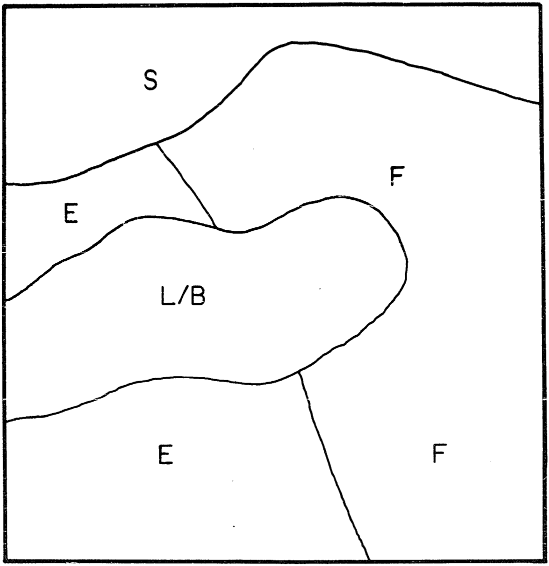


Figure 17. Classification of Area 1 by VP-8 density slicing of a LANDSAT 1:1,000,000 scale band 6 positive transparency. See Figure 15 for legend.

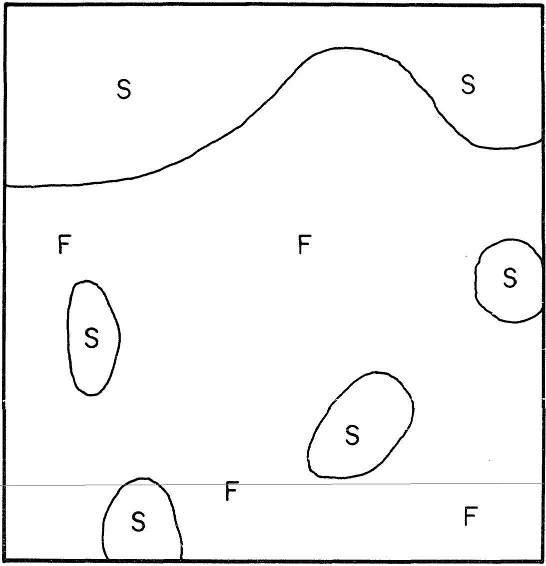


Figure 18. Classification of Area 1 by visual interpretation of a LANDSAT 1:1,000,000 scale band 6 positive transparency. See Figure 15 for legend.

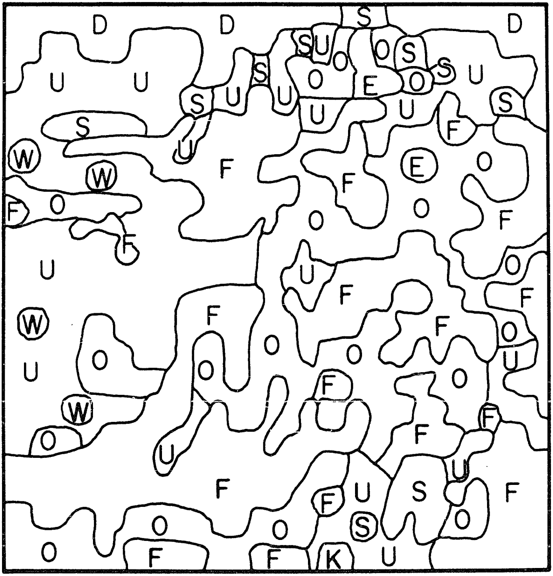


Figure 19. Classification of Area 1 by heuristic algorithmic processing of LANDSAT digital data. See Figure 15 for legend.

Figure 20. Classification of Area 1 by maximum likelihood algorithmic processing of LANDSAT digital data.

Legend: 1 - Fell fields

2 - Alpine tundra

3 - Eriophorum tussocks

4 - Dryas community

5 - Light colored rock or gravel

6 - Shallow water

7 - Deep water

8 - Wet sedge meadow

9 - Wet sedge meadow

10 - Low density white spruce

11 - White spruce forest

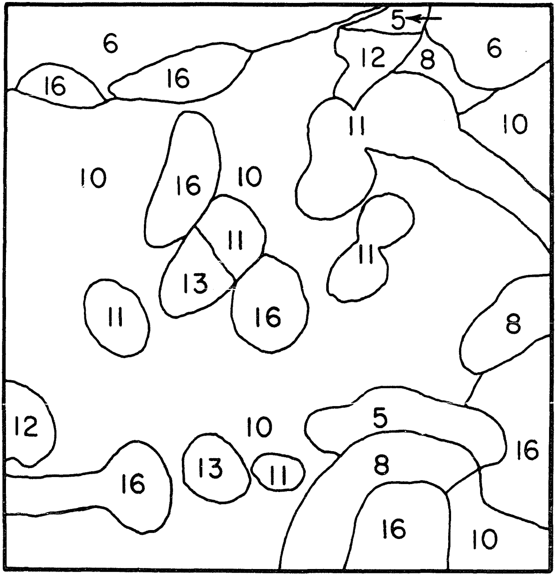
12 - Lichen rich tundra

13 - Undefined

14 - High brush

15 - Undefined

16 - Unclassified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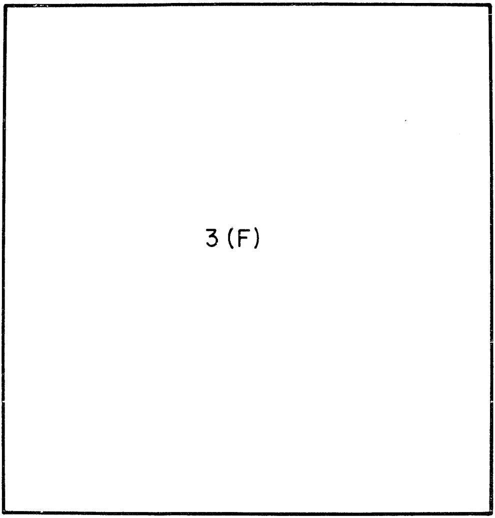

Figure 21. Spetzman's (1956) classification of Area 1.

Legend:
1 - High Forest
2 - High Forest
3 - Low Forest
4 - Low Forest
5 - High Brush
6 - Low Brush
7 - Tundra Meadow
8 - Wet Tundra
9 - Barren

See Figure 15 for corresponding letter classifications.

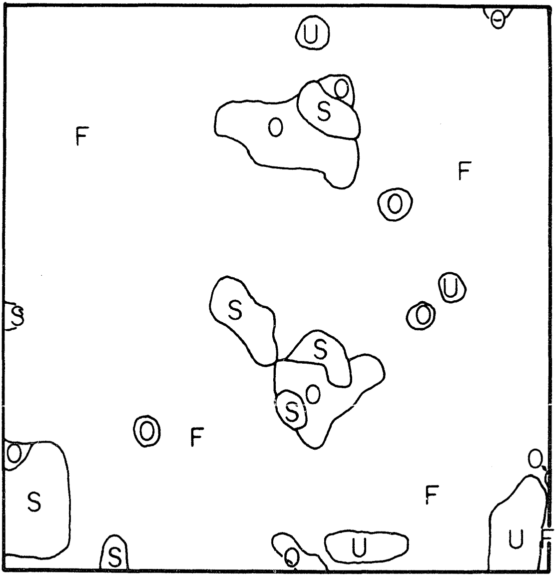

Figure 22. Ground truth classification of Area 2 based on 80 m grid sample points. See Figure 15 for legend.

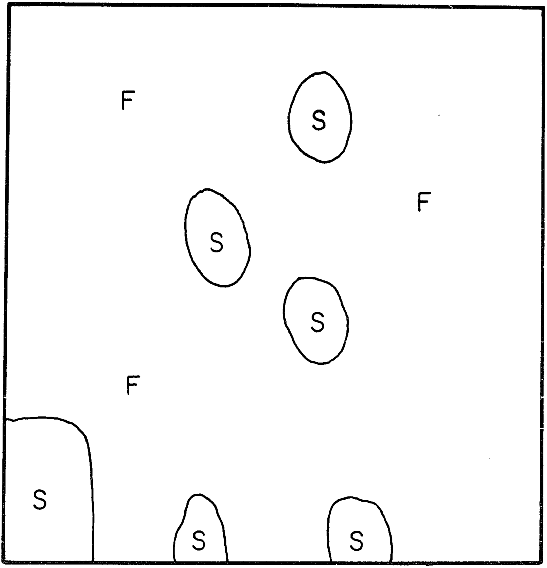

Figure 23. Classification of Area 2 by visual interpretation of a LANDSAT 1:1,000,000 scale band 6 positive transparency. See Figure 15 for legend.

F

Figure 24. Classification of Area 2 by VP-8 density slicing of a LANDSAT 1:1,000,000 scale band 6 positive transparency. See Figure 6 for legend.

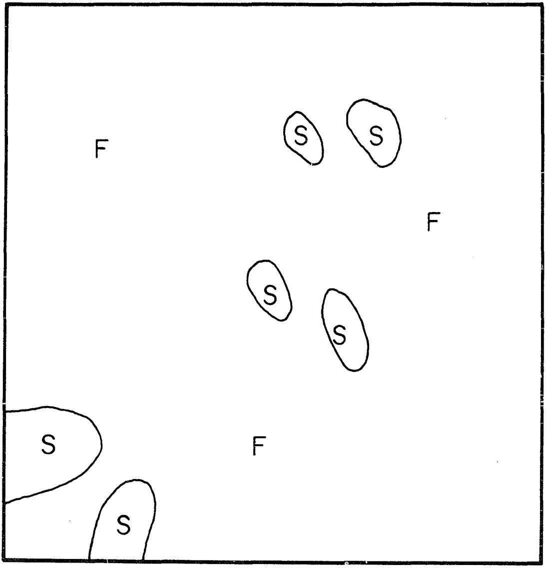

Figure 25. Classification of Area 2 by visual interpretation of a LANDSAT 1:1,000,000 scale band 6 positive transparency. See Figure 15 for legend.

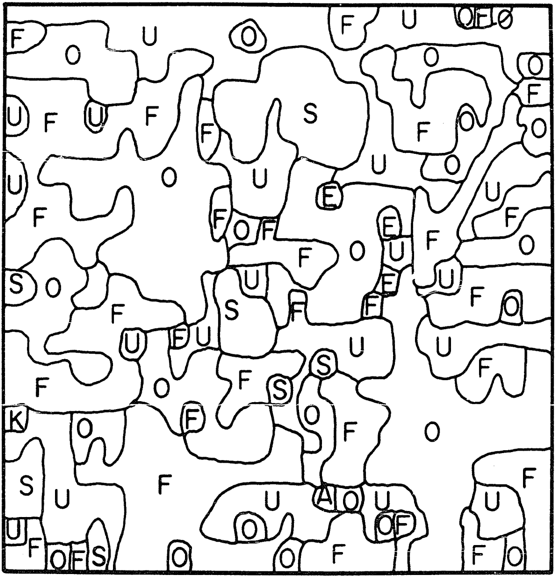

Figure 26. Classification of Area 2 by heuristic algorithmic processing of LANDSAT digital data. See Figure 15 for legend.

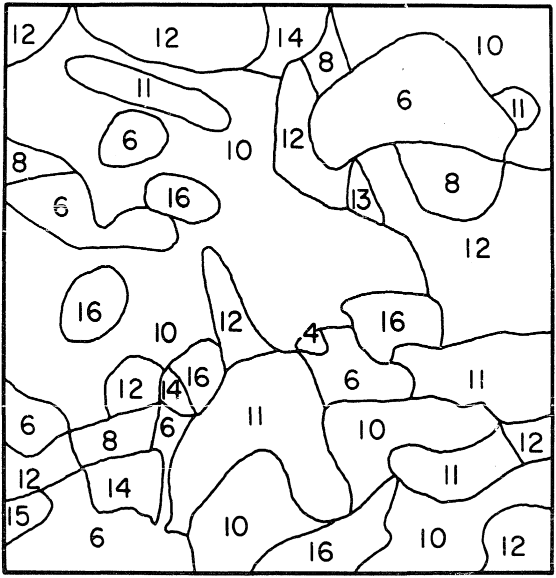

Figure 27. Classification of Area 2 by maximum likelihood algorithmic processing of LANDSAT digital data. See Figure 20 for legend.

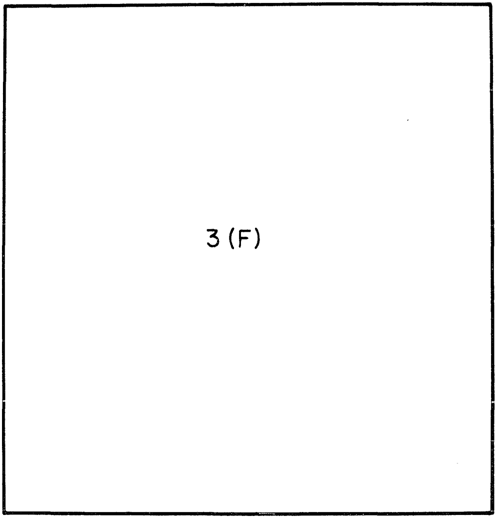

Figure 28. Spetzman's (1956) classification of Area 2. See Figures 15 and 21 for legend.

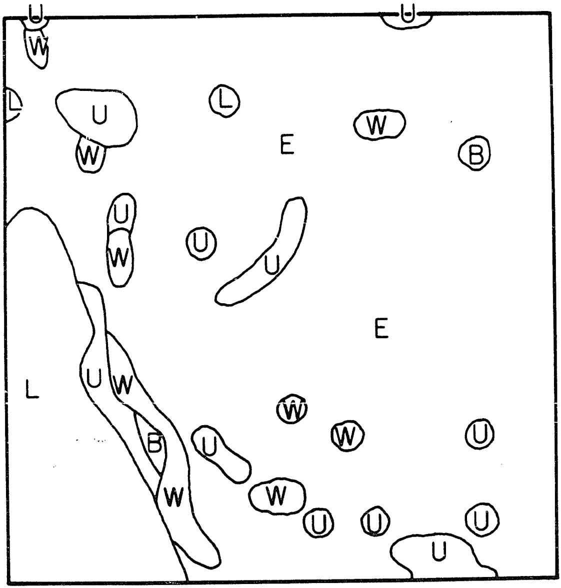

Figure 29. Ground truth classification of Area 3 based on 80 m grid sample points. See Figure 15 for legend.

Figure 30. Classification of Area 3 by visual interpretation of a LANDSAT 1:1,000,000 scale band 6 positive transparency. See Figure 15 for legend.

Upland Brush (L and/or B)

Figure 31. Classification of Area 3 by VP-8 density slicing of a LANDSAT 1:1,000,000 scale band 6 positive transparency. See Figure 15 for legend.

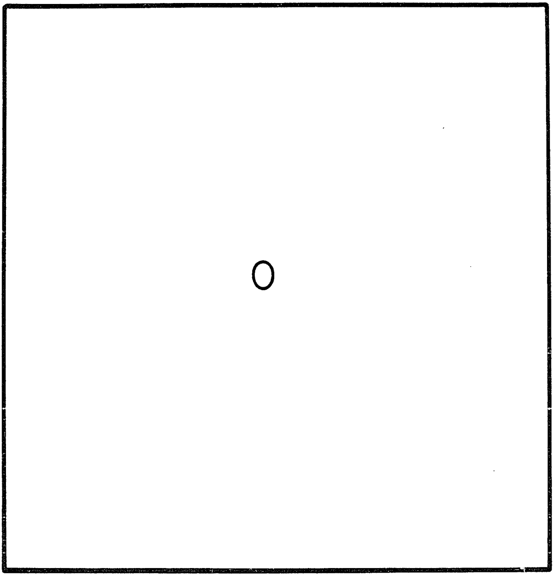

Figure 32. Classification of Area 3 by visual interpretation of a LANDSAT 1:1,000,000 scale band 6 false color transparency. See Figure 15 for legend.

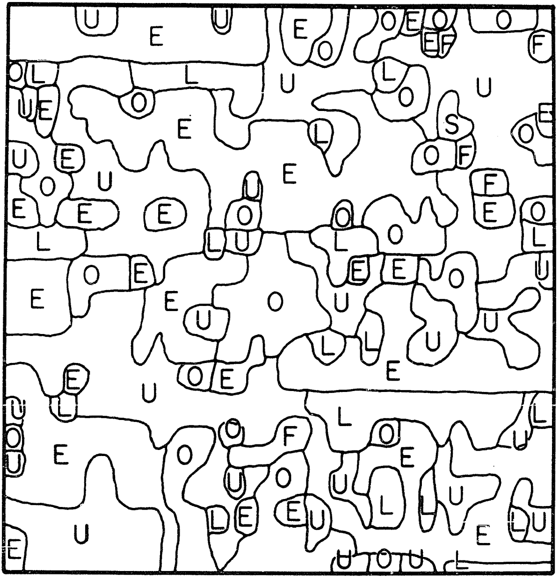

Figure 33. Classification of Area 3 by heuristic algorithmic processing of LANDSAT digital data. See Figure 15 for legend.

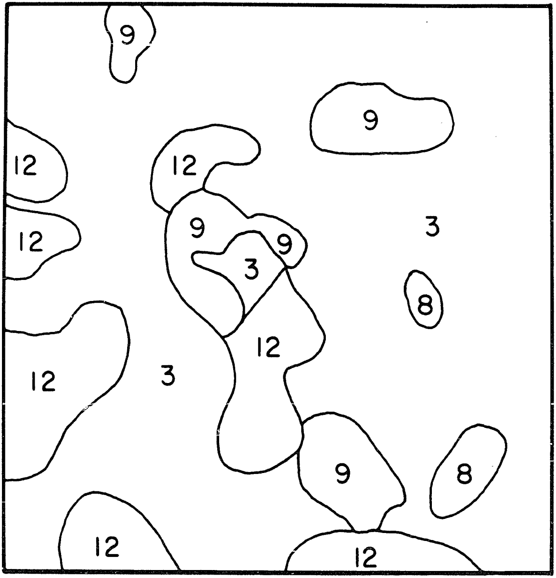

Figure 34. Classification of Area 3 by maximum likelihood algorithmic processing of LANDSAT digital data. See Figure 20 for legend.

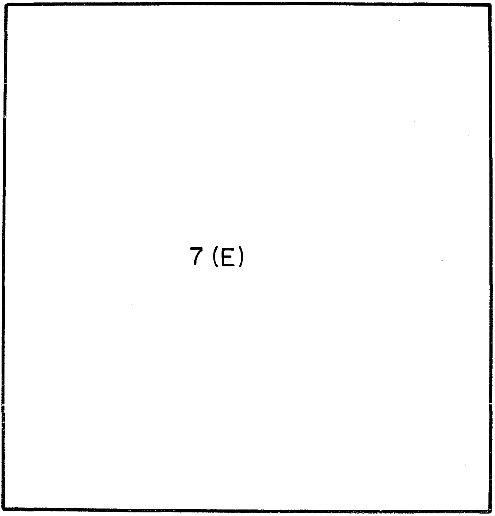

Figure 35. Spetzman's (1956) classification of Area 3. See Figures 15 and 21 for legends.

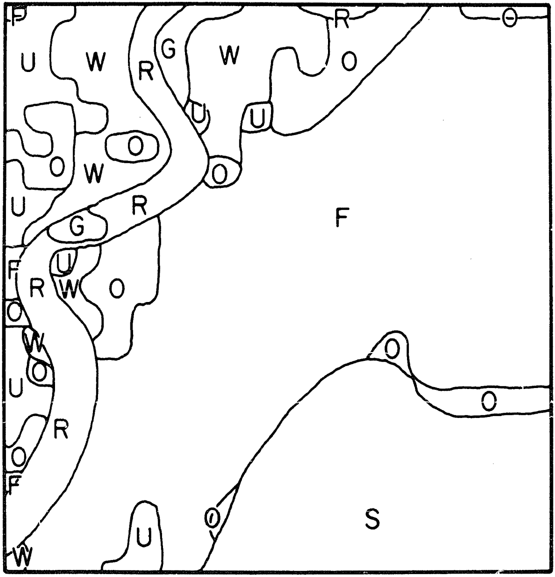

Figure 36. Ground truth classification of Area 4 based on 80 m grid sample points. See Figure 15 for legend.

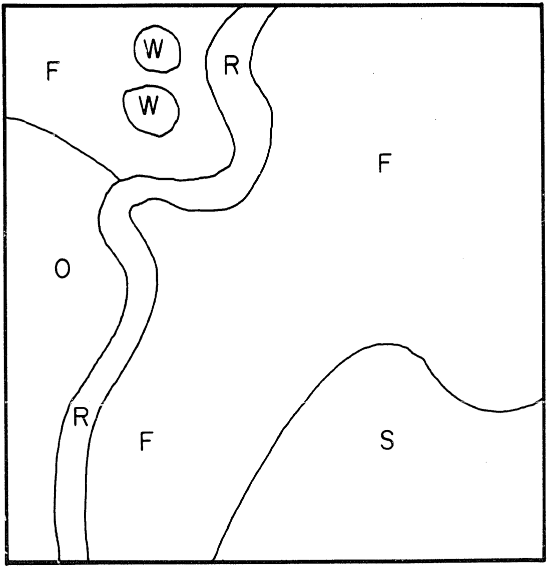

Figure 37. Classification of Area 4 by visual interpretation of a LANDSAT 1:1,000,000 scale band 6 positive transparency. See Figure 15 for legend.

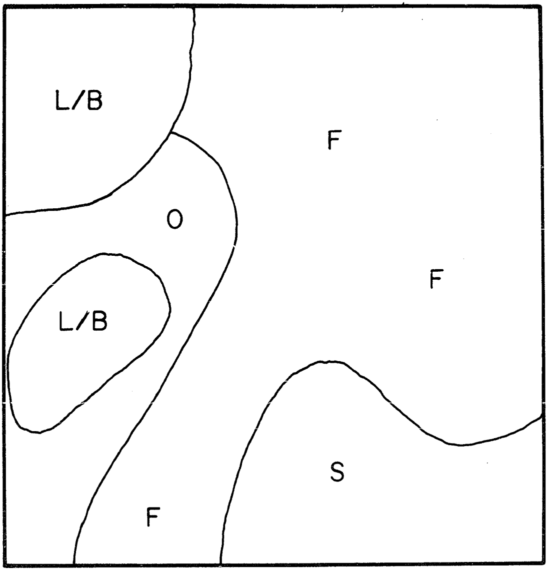

Figure 38. Classification of Area 4 by VP-8 density slicing of a LANDSAT 1:1,000,000 scale band 6 positive transparency. See Figure 15 for legend.

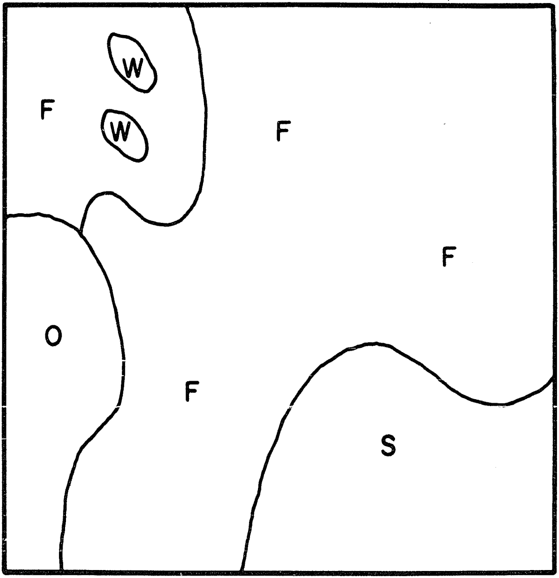

Figure 39. Classification of Area 4 by visual interpretation of a LANDSAT 1:1,000,000 scale false color transparency. See Figure 15 for legend.

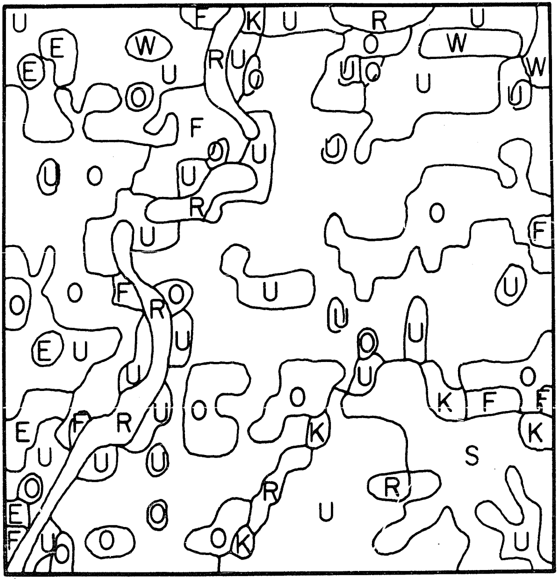

Figure 40. Classification of Area 4 by heuristic algorithmic processing of LANDSAT digital data. See Figure 15 for legend.

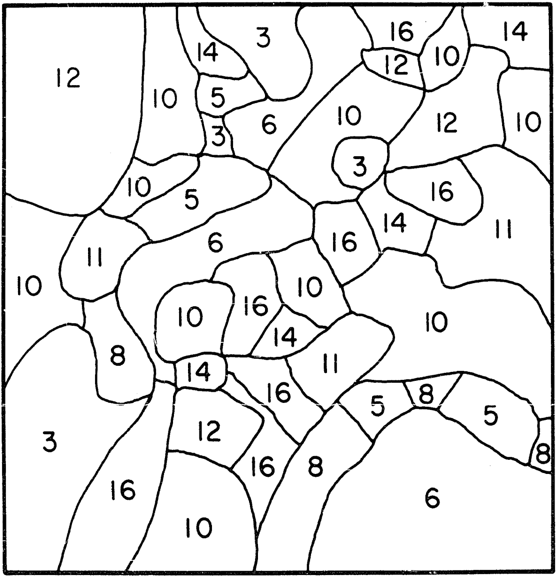

Figure 41. Classification of Area 4 by maximum likelihood algorithmic processing of LANDSAT digital data. See Figure 20 for legend.

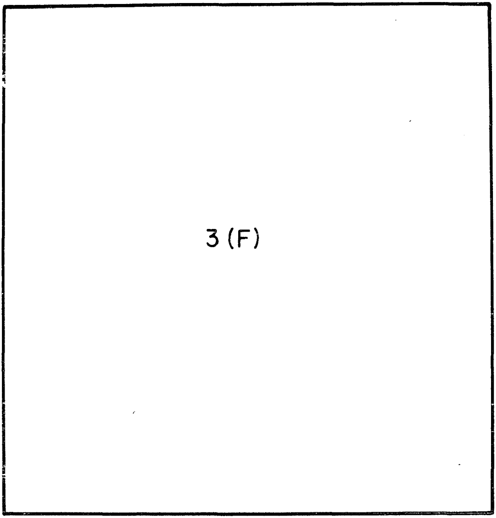

Figure 42. Spetzman's (1956) classification of Area 4. See Figures 15 and 21 for legends.

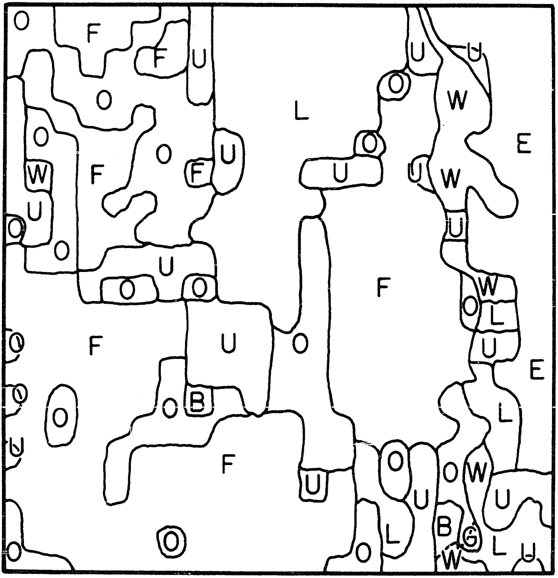

Figure 43. Ground truth classification of Area 5 based on 80 m grid sample points. See Figure 15 for legend.

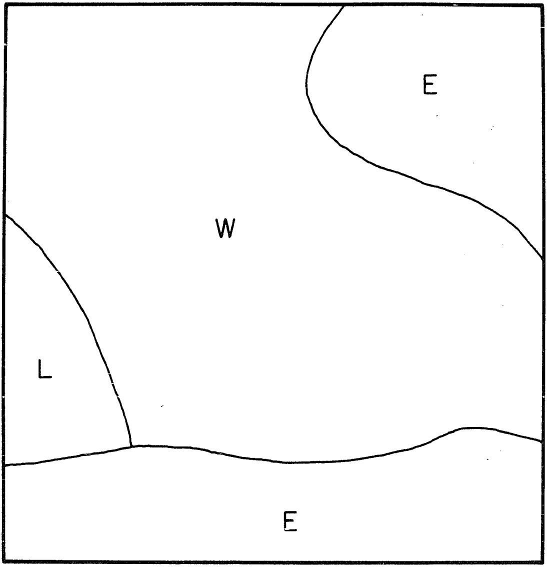

Figure 44. Classification of Area 5 by visual interpretation of a LANDSAT 1:1,000,000 scale band 6 positive transparency. See Figure 15 for legend.

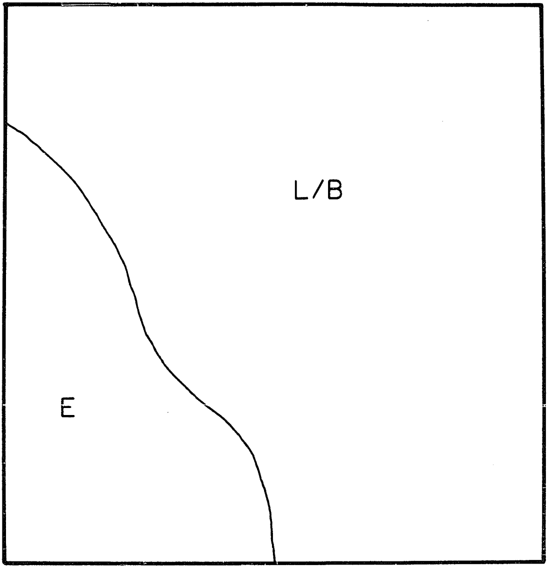

Figure 45. Classification of Area 5 by VP-8 density slicing of a LANDSAT 1:1,000,000 scale band 6 positive transparency. See Figure 15 for legend.

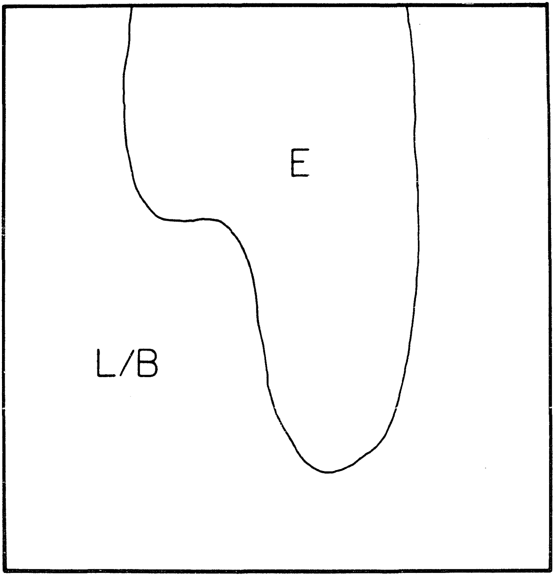

Figure 46. Classification of Area 5 by visual interpretation of a LANDSAT 1:1,000,000 scale band 6 false color composite transparency. See Figure 6 for legend.

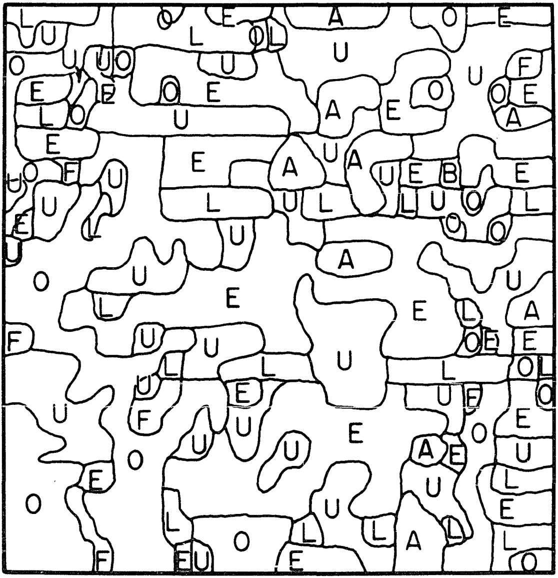

Figure 47. Classification of Area 5 by heuristic algorithmic processing of LANDSAT digital data. See Figure 15 for legend.

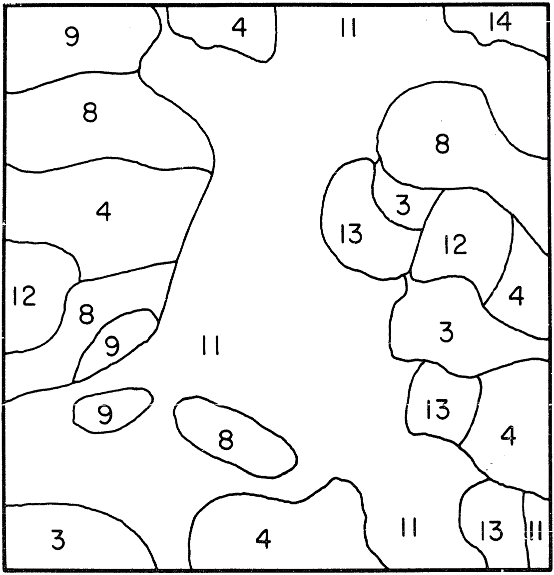

Figure 48. Classification of Area 5 by maximum likelihood algorithmic processing of LANDSAT digital data. See Figure 20 for legend.

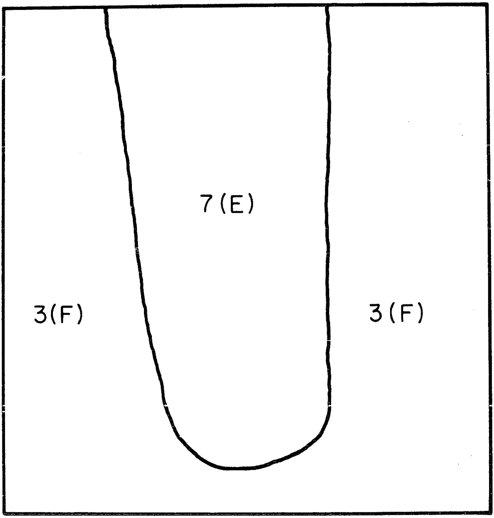

Figure 49. Spetzman's (1956) classification of Area 5. See Figures 15 and 21 for legends.

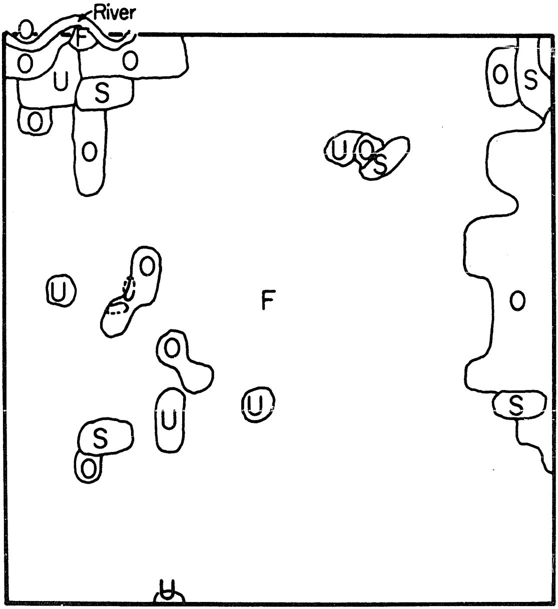

Figure 50. Ground truth classification of Area 6 based on 80 m grid sample points. See Figure 15 for legend.

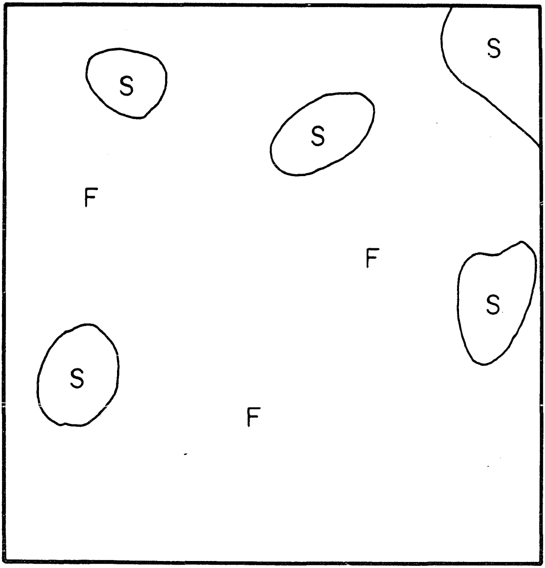

Figure 51. Classification of Area 6 by visual interpretation of a LANDSAT 1:1,000,000 scale band 6 positive transparency. See Figure 15 for legend.

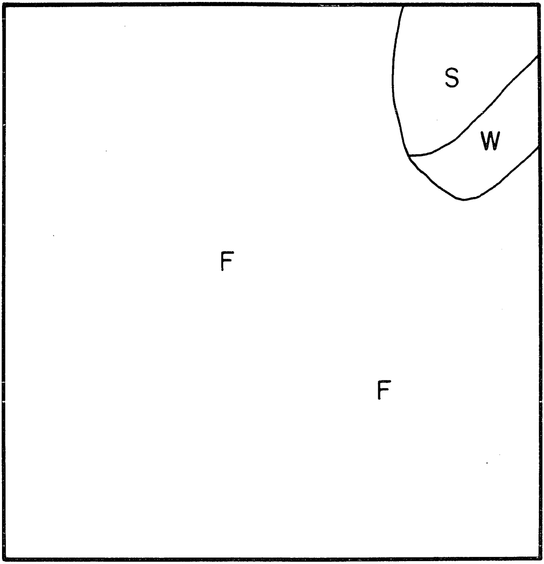

Figure 52. Classification of Area 6 by VP-8 density slicing of a LANDSAT 1:1,000,000 scale band 6 positive transparency. See Figure 15 for legend.

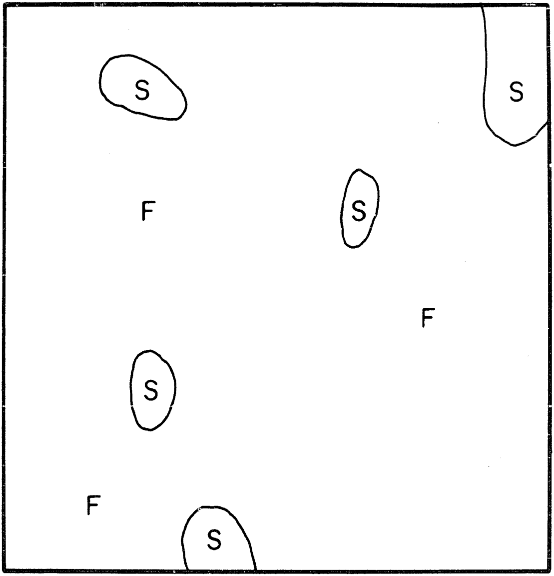

Figure 53. Classification of Area 6 by visual interpretation of a LANDSAT 1:1,000,000 scale false color composite transparency. See Figure 15 for legend.

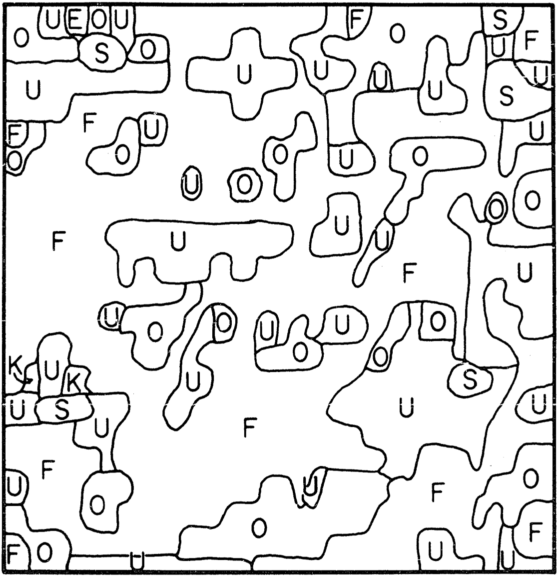

Figure 54. Classification of Area 6 by heuristic algorithmic processing of LANDSAT digital data. See Figure 15 for legend.

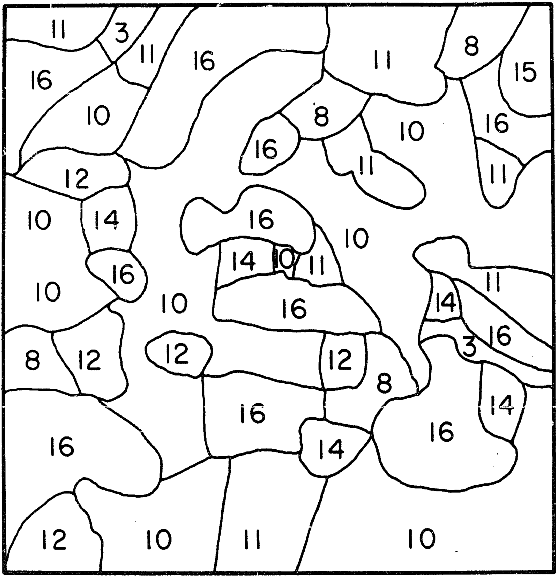

Figure 55. Classification of Area 6 by maximum likelihood algorithmic processing of LANDSAT digital data. See Figure 20 for legend.

3 (F)

Figure 56. Spetzman's (1956) classification of Area 6. See Figures 15 and 21 for legends.

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