Vegetation Mapping of Nowitna National Wildlife Refuge, Alaska Using Landsat MSS Digital Data

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ABSTRACT: A Landsat-derived vegetation map was prepared for Nowitna National Wildlife Refuge. The refuge lies within the middle boreal subzone of north central Alaska. Seven major vegetation classes and sixteen subclasses were recognized: forest (closed needleleaf, open needleleaf, needleleaf woodland, mixed, and broadleaf); broadleaf scrub (lowland, alluvial, subalpine); dwarf scrub (prostrate dwarf shrub tundra, dwarf shrub-graminoid tussock peatland); herbaceous (graminoid bog, marsh and meadow); scarcely vegetated areas (scarcely vegetated scree and floodplain); water (clear, turbid); and other areas (mountain shadow).

The methodology employed a cluster-block technique. Sample areas were described based on a combination of helicopter-ground survey, aerial photointerpretation, and digital Landsat data. Major steps in the Landsat analysis involved preprocessing (geometric correction), derivation of statistical parameters for spectral classes, spectral class labeling of sample areas, preliminary classification of the entire study area using a maximum-likelihood algorithm, and final classification utilizing ancillary information such as digital elevation data.

The final product is a 1:250,000-scale vegetation map representative of distinctive regional patterns and suitable for use in comprehensive conservation planning.

INTRODUCTION

As part of developing comprehensive conservation plans for 16 refuges in Alaska, the Alaska National Interest Lands Conservation Act of 1980 requires the U.S. Fish and Wildlife Service to identify and describe the wildlife habitats of Nowitna National Wildlife Refuge (NWR). A vegetation map was necessary to examine these habitats because they are essentially a vegetational phenomenon (Egler, 1977).

Published vegetation maps that include the refuge, such as that produced by Küchler (1966; scale 1:7,500,000), contained classes that were too broad to convey much information appropriate for planning. The most practical approach to refuge vegetation mapping seemed to be a Landsat-assisted approach for several reasons: (1) planners required intermediate-scale maps (1:250,000) that could be efficiently registered to other data bases; (2) the refuges covered vast, remote areas ranging from 129 to 7,942 km^2; (3) short completion time (five years to map 30,780 km^2); and (4) incomplete availability of aerial photographs.

The specific objectives of this report include (1) presentation of a Landsat-derived vegetation map showing the distribution of vegetation types within Nowitna NWR and (2) description of the variation in the physiognomy and composition of the vegetation in relation to broad ecological factors. The classification is a first approximation, preparing the way for more detailed quantitative methods.

GEOGRAPHICAL SETTING

The study area is the Nowitna NWR (836,376 ha), located in north central Alaska. The refuge lies within two land resource areas: Interior Alaska Lowlands (Tanana-Kuskokwim subclass) and the Kuskokwim Highlands (Rieger *et al.*, 1979).

Soil development occurs on several surficial geological types: alluvial, glacial, lacustrine, eolian, and colluvial (Karlstrom *et al.*, 1964). Three soil orders are represented—Inceptisols, Histosols, and Entisols. The most widespread soil subgroups are Histic Pergelic Cryaquepts and Typic Cryochrepts (Rieger *et al.*, 1979).

The climate is cold and continental, with the average annual temperature and precipitation at Galena (100 km to the west) of −4.7°C and 330 mm, respectively. The study area is situated within the 'middle boreal subzone' (mean annual biotemperature = 4.6°C) (Hämet-Ahti *et al.*, 1974).

Vegetation maps of Alaska published by Küchler (1966; scale 1:7,500,000) and the Joint Federal-State Land Use Planning Commission for Alaska (1973; 1:2,500,000) are similar. Classes recognized by Küchler (1966) are (1) spruce-birch forest (*Picea-Betula*), (2) spruce forest (*Picea*), (3) alder thicket (*Alnus*), (4)

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muskeg (*Eriophorum-Sphagnum-Betula*), and (5) dryas meadows and barren (*Dryas-Carex-Betula*).

METHODS

Steps used in developing the map follow.

INVENTORY

Prior to the field investigation, three Landsat multispectral scanner (MSS) scenes (#17732-10255 and -10325, 4 September 1974, and #25372-10555, 12 July 1976) that together covered the entire refuge were acquired. Seven sampling areas (*ca*. 11 by 11 km) or training blocks were selected from the scenes within the adjacent to the refuge by visually interpreting the Landsat images and locating the blocks in areas that represented the totality of spectral variation (Figure 1). An eighth block (H) located outside the refuge was selected and added from a scene that overlapped Koyukuk NWR where we were conducting similar mapping studies. The eight-block total extended the range of spectral reflectance patterns, vegetation, and terrain conditions within the refuge. Other criteria for training block selection included differences in landforms, soils, surficial geology, and spatial distribution. Color infrared aerial photographs (scale 1:60,000) were obtained for each training block. The photographs were interpreted using stereo triplets and spectrally homogeneous units or polygons were delineated.

Following an aerial reconnaissance of the study area, a combined helicopter-ground survey was conducted. In this survey, vegetation description was accomplished at two levels: general and detailed. At the general level, the physiognomy and dominant woody species were recorded for each polygon. All polygons were classified using a combination of the UNESCO (1973) and Ellenberg and Mueller-Dombois (1967) systems. Sampling intensity ranged from 10 to 20 polygons per training block. At the detailed level, quantitative descriptions of the floristic composition, structure, and major site features of stands selected to represent the spectrum of major environmental and vegetational variation were recorded.

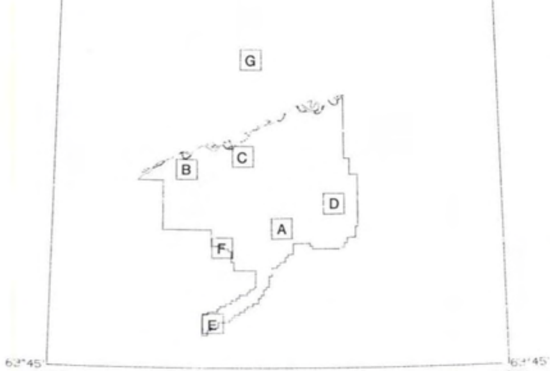

FIG. 1. Map of Nowitna National Wildlife Refuge showing training block locations.

To be acceptable for sampling, a stand had to be homogeneous and representative of the community from which it was sampled. Stand descriptions were from single plots and employed a 10- by 10-m quadrat for non-forest vegetation and a 20- by 20-m quadrat for forest vegetation. Cover values were estimated for each species for seven cover-abundance classes (Westhoff and Maarel, 1973).

PREPROCESSING

The Landsat scenes covering the refuge were obtained in computer compatible tape format. All digital processing was conducted at the U.S. Geological Survey, EROS Field Office, Anchorage, on the Interactive Digital Image Manipulation System* (IDIMS) (ESL Incorporated, 1981). Geometric correction of the Landsat subscene to a Universal Transverse Mercator (UTM) projection was performed to allow for registration of other related data sets, e.g., terrain information, refuge boundary, and Landsat MSS winter data, to the classified image. For scene registration, three points were located on each USGS topographic map (scale 1:63,360) and the corresponding points were located on the scene by viewing the image on a color monitor. The 36 points covering the Landsat scene were used to define second-order, least-squares polynomial transformations relating UTM Northing and Easting values on the maps to row and column position for each of the Landsat scenes. These transformation coefficients rectified the Landsat scenes to a UTM projection with 50-m^2 picture elements (pixels). Examination of mean residual errors associated with the second-order transformation equation indicated a registration accuracy of $\pm$one pixel. The final registered Landsat image consisted of four MSS bands comprised of 3,600 rows by 3,800 columns.

DEVELOPMENT OF TRAINING CLASSES AND ASSOCIATED STATISTICS

A cluster-block approach (Fleming, 1975) was used to develop training classes. A clustering algorithm (ISOCLS) was used to define discrete groups of pixels (clusters) on the basis of their reflectance in the four Landsat spectral bands. The eight sample blocks were grouped into five sets of two blocks each (blocks A + B, C + D, E + F, E + G, C + H). Each set was used in the clustering algorithm. It was arbitrarily specified that 40 discrete clusters be produced. The algorithm classified pixels of similar reflectance values,

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maximized statistical distance between classes of dissimilar pixels, and provided statistical estimates (mean vector and covariance matrix) for the individual classes.

Generating two sets of statistics provided two independent estimates of the spectral properties of the scenes being analyzed. Following statistical tests for cluster separability, the two files were merged into one statistical file of 54 spectral classes. Clusters that contained redundant or overlapping mean spectral reflectance values were either combined into one cluster, or one of the redundant files was deleted. After establishing the pooled file, analysis of the field data and aerial photographs was initiated.

Spectral Class Labeling

Spectral classes were assigned to individual vegetation classes using vegetation field data and high-altitude color infrared aerial photographs. Spectral classes were displayed on the color monitor from each training block. Individual spectral classes were compared to the corresponding vegetation polygons identified from manually interpreted and field verified aerial photographs. Inconsistencies in class composition were documented for later refinement in the post-classification phase. Figure 2 provides a two-dimensional illustration of the final spectral classes in relation to vegetation subclasses.

Several spectral classes contained more than one vegetation category. Most frequently these occurred where (1) variation in slope and aspect caused inconsistent reflectance properties or (2) different vegetation types had similar reflectance properties because of terrain influence. Site moisture was another factor altering the reflectance characteristics of a vegetation type. Dwarf shrub wetlands were consistently mistaken for open and closed conifer forests, because all have low reflectance in the infrared. A solution to this problem is described in the post-classification refinement phase.

Classification

The training class statistical file developed within training blocks was applied outside the blocks to the entire three-scene mosaic using a maximum-likelihood classification algorithm. The algorithm compared the reflectance value of each pixel to the mean and covariance matrix values obtained for each spectral class and assigned it to the class for which its probability of membership was highest. Thus, every pixel in the study area was assigned to one of the spectral classes, developed and labeled in the previous phases, resulting in a preliminary vegetation map.

Post-Classification Refinement

The accuracy of the preliminary vegetation map was evaluated visually by the analysts to determine whether classes developed within training blocks were correlated with those outside the blocks.

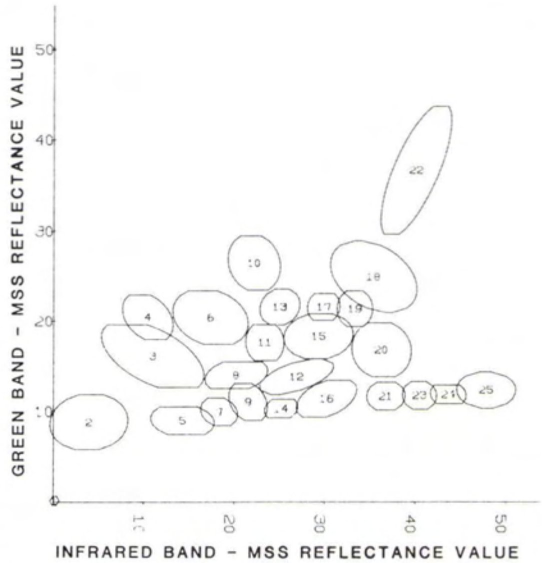

FIG. 2. Cluster diagram for Nowitna National Wildlife Refuge Landsat scenes, bands 2 (green) and 4 (near IR). Key:

Vegetation Subclass	Cluster Number
Closed Needleleaf Forest	5
Open Needleleaf Forest	9
Needleleaf Woodland	12
Mixed Forest	7
Deciduous Forest	14, 16, 21, 23; 24, 25 (in part *)
Lowland Scrub	8, 11
Alluvial Scrub	10
Subalpine Scrub	24, 25 (in part*)
Dwarf Scrub - Graminoid Tussock Peatland	15 (in part *), 19
Prostrate Dwarf Shrub Tundra	20 (in part *)
Graminoid Bog, Marsh, and Meadow	20, 15 (in part **)
Scarcely Vegetated	13, 17, 18, 22
Clear Water/Shadow	2, 3
Turbid Water	4, 6

*Separated using ancillary elevation data.
**Separated using ancillary elevation data and ecological mask.

Nowitna NWR staff biologists with considerable field experience contributed to the assessment. Classification problems were evident where spectral classes contained more than one vegetation class due to the influence of terrain or site moisture. To reduce classification errors, two ancillary data types—Digital Elevation Model (DEM) and winter Landsat MSS data—were registered and integrated into the data base.

DEM data, produced by digitizing elevation contours from USGS topographic maps (scale 1:250,000), were registered to the Landsat MSS data. IDIMS algorithms were subsequently used to derive slope and aspect from the elevation data to provide three terrain-related data sets to complement the

Landsat classification data. Knowledge gained from field observations and experience was then used to correct classification errors. For example, (1) DEM slope and aspect classes were used to distinguish mountain shadows from water, (2) elevation data were used to separate lowland scrub classes from subalpine scrub, and (3) elevation and aspect data were used to label spectral classes on north and northwest aspects which were in shadow due to their position on the terrain.

Winter Landsat MSS data were used to correct the classification problem caused by site moisture. Wetland communities that have open standing water tend to have much lower mean reflectance values due to the low reflectance of near infrared radiation by water. Accordingly, dwarf shrub wetlands have a spectral signature very similar to coniferous forest. As a solution, winter Landsat MSS data (band 7) were registered and analyzed. Wetland communities are normally frozen and covered with an even layer of snow in winter, and are thus distinguished by higher reflectance on a winter Landsat scene from taller communities such as conifer forests. A density slice was performed on the winter data and a mask of all areas having a brightness value greater than that associated with areas of forest or scrub was generated. This mask was applied to the classified summer data to stratify and correct the misclassified wetland and forest communities.

RESULTS

Seven major classes and sixteen subclasses were distinguished on the Landsat-derived vegetation map (Plate 1). The acreages and percentages for each vegetation type are given in Table 1. Descriptions of the map classes follow.

FOREST

Forest is formed of tree species at least 5 m tall and immature trees in intermediate successional stages that have not yet reached 5 m in height. The forest class, the most widespread vegetation type, covers 88 percent of the refuge. The major forest subclasses identified are closed needleleaf, open needleleaf, needleleaf woodland, mixed, and broadleaf. Of these subclasses, open needleleaf and broadleaf are the most extensive.

CLOSED NEEDLELEAF FOREST. Cover of trees in this subclass ranges from 60 to 100 percent. This subclass predominates on moist to well drained sites from the lowlands to mountain slopes and is particularly well developed on alluvial sites where it is distinguished by high growth rates. Accordingly, alluvial forests are taller than contiguous non-alluvial forest communities. The dominant coniferous tree of alluvial forest is *Picea glauca*. Deciduous tree species such as *Betula papyrifera* and *Populus balsamifera* represent a minor component. The understory is characterized by shrubs such as *Alnus crispa, Rosa acicularis, Viburnum edule*, dwarf shrubs, *Vaccinium vitis-idaea, Linnaea borealis*, herbs, *Galium boreale, Pyrola* spp., *Mertensia paniculata, Aster sibiricus*, and *Hedysarum alpinum*. Feathermosses, primarily *Hylocomium splendens* and *Ptilium crista-castrensis*, are abundant. *Picea glauca* is an upland species in the study area and seldom occurs on wet sites, whereas *Picea mariana* is a lowland species that can occur in the upland.

OPEN NEEDLELEAF FOREST. Open stands of trees with 25 to 60 percent cover form this subclass. It is usually dominated by *Picea mariana*. On moderately to poorly drained mineral soils, the forest understory contains the shrub, *Alnus crispa*, dwarf shrubs, *Ledum groenlandicum, Vaccinium uliginosum, V. vitis-idaea, Rosa acicularis*, feathermosses, *Hylocomium splendens* and *Pleurozium schreberi*, and lichens, *Cladina* spp., and *Nephroma arcticum*.

Open needleleaf forests also develop on shallow organic deposits forming *Picea mariana* or *Larix laricina* wetlands. They are characterized by dwarf shrubs, *Ledum groenlandicum, L. decumbens*, graminoids, *Eriophorum vaginatum* and *Carex bigelowii*, forb, *Rubus chamaemorus*, mosses, *Hylocomium splendens, Pleurozium schreberi* and *Polytrichum* spp. and lichen, *Cladina* spp.

NEEDLELEAF WOODLAND. This is an open forest type with tree cover ranging from 10 to 25 percent. Dwarf shrubs assume a major role in the understory. In lowland sites the soils are usually poorly drained. *Picea mariana* is the most common tree species. The shrub layer is usually sparse and characterized by *Betula glandulosa*. The rich dwarf shrub stratum is dominated by the species *Ledum decumbens, Vaccinium uliginosum, V. vitis-idaea, Oxycoccus microcarpus, Empetrum nigrum*, and *Andromeda polifolia*. Also characteristic are tussock-forming graminoids, *Eriophorum vaginatum, Carex bigelowii*, and the forb, *Rubus chamaemorus*. Important mosses are *Hylocomium splendens, Pleurozium schreberi, Sphagnum fuscum, Aulacomnium* spp. and lichens, *Cetraria* spp., *Cladina* spp., and *Nephroma arcticum*.

On well drained sites in the mountains, subalpine *Picea glauca* woodlands develop. The understory usually contains deciduous scrubs, *Alnus crispa* and occassionally *Salix*.

MIXED FOREST. Deciduous broadleaf and evergreen needleleaf coniferous trees with 25 to 100 percent cover form this subclass. It occurs on well to moderately drained mineral soils in the lowlands and montane zone. Principal broadleaf species are *Betula papyrifera* and *Populus tremuloides*, while the predominant coniferous tree is *Picea glauca*. The understory of mixed forest is characterized by shrubs, *Rosa acicularis, Ribes triste*, dwarf shrubs, *Linnaea borealis*, and herbs, *Mertensia paniculata*, and *Cornus canadensis*.

This subclass also includes some open needleleaf forests with an understory of deciduous shrubs, *Alnus*, because deciduous shrubs and trees are difficult to distinguish on Landsat data.

BROADLEAF FOREST. In deciduous broadleaf forest (25 to 100 percent cover) the majority of trees shed their foliage simultaneously in connection with winter frost. Deciduous broadleaf trees, *Betula papyrifera, Populus tremuloides*, and *Populus balsamifera* are dominant, but evergreen tree species, particularly *Picea glauca*, may be present as part of the main canopy or in the understory. The mineral soils supporting broadleaf forests are usually well to imperfectly drained.

One major subtype, alluvial deciduous forest, is dominated by *Populus balsamifera* and typically underlain by regenerating white spruce. The understory is composed of a shrub stratum of *Alnus incana, Cornus*

PLATE 1. Vegetation map of Nowitna National Wildlife Refuge, Alaska.

stolonifera, *Rosa acicularis*, and *Viburnum edule*. Alluvial forests of *Betula papyrifera* and *Populus tremuloides* also develop.

On hilly or montane sites *Betula paprifera* forests occur as strips on relatively nutrient rich, better drained soils within a landscape dominated by open *Picea mariana* forests and woodlands. The understory is characterized by the shrub, *Alnus crispa*, dwarf shrubs, *Rosa acicularis, Ribes triste*, herb, *Cornus canadensis*, and the grass, *Calamagrostis canadensis*.

South-facing dunes often support open *Populus tremuloides* woodlands and steppe vegetation. These dry, well-drained sites occur in central eastern portions of the refuge. Typical species are trees, *Populus tremuloides*, shrubs, *Shepherdia canadensis, Rosa acicularis*, dwarf shrubs, *Arctostaphylos uva-ursi*, and grasses, *Calamagrostis purpurascens* and *Bromus pumpellianus*. Other relatively level sandy sites support lichen-dominated aspen woodlands.

The broadleaf forest subclass includes some broadleaf scrub communities as the two form a structural continuum and are spectrally similar. This is particularly true along major rivers where the shrub *Salix alaxensis* attains tree stature.

Scrub

This vegetation class is predominantly composed of shrubs ranging between 0.5 and 5 m in height that shed their foliage simultaneously in winter. Scrub occurs primarily along water courses, poorly drained sites, and in the alpine and subalpine zones.

SUBALPINE BROADLEAF SCRUB. Occurring above

TABLE 1. RELATIVE ABUNDANCE OF VEGETATION CLASSES AND SUBCLASSES WITHIN NOWITNA NWR.

Vegetation Class	Surface Area Hectares	Surface Area Percent
FOREST		
Closed Needleleaf Forest	17,497	2.1
Open Needleleaf Forest	350,097	41.9
Needleleaf Woodland	85,691	10.2
Mixed Forest	34,371	4.1
Broadleaf Forest	247,527	29.6
SCRUB		
Lowland Broadleaf	28,419	3.4
Alluvial Broadleaf	1,898	0.2
Subalpine Broadleaf	6,636	0.8
DWARF SCRUB		
Dwarf Shrub-Graminoid Tussock Peatland	15,179	1.8
Prostrate Dwarf Shrub Tundra	400	0.1
HERBACEOUS		
Graminoid Bog, Marsh, and Meadow	14,588	1.7
SCARCELY VEGETATED AREAS		
Scarcely Vegetated Floodplain	263	0.1
Scarcely Vegetated Scree	11	0.0
WATER		
Clear	20,416	2.4
Turbid	2,472	0.3
SHADOW	10,911	1.3
Total	836,376	100.0

timberline, this subclass is dominated by the shrubs, *Alnus crispa* and *Salix planifolia* spp. *pulchra* and *Spiraea beauverdiana*. The understory is mainly composed of dwarf shrubs, *Vaccinium vitis-idaea* and *Linnaea borealis*. The herb stratum is exemplified by *Rubus arcticus*, *Lycopodium annotinum*, and *Calamagrostis canadensis*.

A second major subalpine scrub type is dominated by *Betula glandulosa* and *Vaccinium uliginosum*. It usually occurs between subalpine *Alnus* scrub and alpine *Dryas* tundra. It is lower in stature than alder scrub.

LOWLAND BROADLEAF SCRUB. This subclass is found on poorly drained sites in the lowlands. It is often associated with *Calamagrostis canadensis* meadows in dried oxbow lakes. The overstory is dominated by willows, particularly *Salix planifolia* ssp. *pulchra* with an understory of *Calamagrostis canadensis*.

ALLUVIAL BROADLEAF SCRUB. Found on frequently flooded sites, this subclass is dominated by *Salix alaxensis*. In certain areas, however, *Alnus incana* and *Alnus crispa* predominate. The chief understory species is *Equisetum arvense*. Alluvial deciduous scrub colonizes a zone along river banks between riverine grasslands or horsetail communities and balsam poplar forests. This subclass is also found in the montane zone and at high elevation alluvial sites near the treeline where *Salix planifolia* spp. *pulchra* predominates.

DWARF SCRUB

This vegetation class is composed of slow growing dwarf shrubs less than 0.5 m, chiefly Ericaceae and Empetraceae. An abundance of mosses and lichens grow amid the dwarf shrubs. Within the class two subclasses are recognized: prostrate dwarf shrub tundra and dwarf shrub-graminoid tussock peatland.

PROSTRATE DWARF SHRUB TUNDRA. This subclass refers to relatively bare, alpine tundra. The term 'tundra' as used here refers to low growing vegetation above the limit of continuous forests in the mountains. It is dominated by matted dwarf shrubs, especially *Dryas octopetala*, and often includes *Salix phlebophylla*, *Vaccinium uliginosum*, *V. vitis-idaea*, *Empetrum nigrum*, *Diapensia lapponica*, *Salix arctica*, and *Arctostaphylos alpina*. It is also rich in lichens: *Sphaerophorus globosus*, *Cetraria nivalis*, *C. cucullata*, *Alectoria ochroleuca*, *Thanmolia subuliformis*, and *Stereocaulon* ssp. Other characteristic species include *Pedicularis lanata* and *Hierochloe alpina*. Portions of erect dwarf shrub tundra characterized by *Betula glandulosa*, *Ledum decumbens*, and *Vaccinium uliginosum* are included in this subclass.

DWARF SHRUB-GRAMINOID TUSSOCK PEATLAND. Peatland refers to terrain covered by peat. The organic soils of this subclass are poorly to very poorly drained. The following species predominate: dwarf shrubs, *Ledum decumbens*, *Vaccinium uliginosum*, *V. vitis-idaea*, and *Betula glandulosa*; tussock graminoids, *Eriophorum vaginatum* and *Carex bigelowii*; forbs, *Rubus chamaemorus*; mosses, *Sphagnum* spp.; and *Dicranum* spp., and lichens, *Cladina* spp. and *Cetraria* spp.

Two vegetation types, raised ombrotrophic peat plateau complex and string bogs, are included under the broad category of dwarf shrub-graminoid tussock peatland subclass because they contain a rich dwarf shrub component and could not be spectrally distinguished from them in the Landsat analysis.

Raised ombrotrophic peat plateau complex is a raised bog type and develops in portions of nearly level lowlands. As peat accumulates by the growth of *Sphagnum* and other species, a bog is formed with a raised surface that prevents the inflow of water from mineral soil. These bogs are dependent on precipitation for water and nutrients. The dominant peat material is shallow to deep fibric sphagnum peat. The bog has an elevated surface that is generally flat. Low fertility and pH of the peat are characteristic. The soils are dominantly cryofibrists. Characteristic species associated with this raised bog type are: tree, *Picea mariana*, dwarf shrubs, *Ledum decumbens, Andromeda polifolia, Oxycoccus microcarpus*, forbs, *Rubus chamaemorus, Drosera rotundifolia;* graminoid, *Eriophorum vaginatum*, moss, *Sphagnum fuscum, Pleurozium schreberi, Mylia anomala*, and lichen *Cladina* spp. This type has scattered trees and grades into needleleaf woodland.

String bogs are a type of organic terrain that develop on water-impermeable material with very flat to nearly imperceptible slopes. They are distinguished by a microrelief that looks like irrigated, terraced-rice fields. From an aerial perspective string bogs offer a striking array of patterns and colors. Primarily due to the sluggish flow in the subsurface layers and frost action, long extended organic ridges or "strings" develop from swept-together, somewhat raised material. String bogs are open bogs that are either devoid of trees or have a few trees of low vigor. When trees (*Larix laricina*) are present, they occur on the strings. Typically, the strings are covered with dwarf shrubs and are rich in *Sphagnum*. Dominant shrub species are: *Betula glandulosa, Vaccinium uliginosum, Ledum decumbens, Chamaedaphne calyculata*, and *Oxycoccus microcarpus*. The string surface is relatively drier than the wetter spaces, termed flarks, which occur between the strings. The flarks usually abound with *Carex* species. Flark composition is typified by the following taxa: *Andromeda polifolia, Carex lasiocarpa, C. aquatilis, C. limosa, C. rostrata, C. chordorrhiza*, and *Sphagnum* spp.

Herbaceous Vegetation

Herbaceous plants are without significant woody tissue and die back to the ground surface each year. There are two major growth forms—graminoids and forbs. Graminoids include all herbaceous grasses and grasslike plants; for example, *Carex* and *Eriophorum*. Forbs are broad-leaved herbaceous plants; for example, *Nuphar* and *Menyanthes*. The primary herbaceous subclass includes graminoid marsh, bog, and meadow. Marshes are wet areas periodically inundated up to a depth of 1 m or less with standing or slowly moving water. The water usually remains within the rooting zone of plants for at least part of the growing season (Jeglum *et al.*, 1974). Meadows are closed herbaceous communities of rather limited extent as opposed to extensive grasslands (Fosberg, 1967). Bogs are peat-covered areas with a high water table and a surface cover of mosses, primarily *Sphagnum* (Jeglum *et al.*, 1974).

GRAMINOID BOG, MARSH, AND MEADOW. This broad wetland type is an agglomeration of three subtypes: (1) Graminoid bog is dominated by graminoids and *Sphagnum*. Typical graminoids are *Eriophorum russeolum, Carex limosa*, and *Carex chordorrhiza*. (2) Graminoid meadow is relatively dry and dominated by *Calamagrostis canadensis*. It is often associated with old meander scars. (3) Graminoid marsh primarily occurs at the margins of lakes and ponds. The most important graminoids are *Carex aquatilis, C. rostrata*, and *Calamagrostis canadensis*.

Scarcely Vegetated Areas

In this class plants are scarce or absent and bare mineral soil or rock determines the overall appearance of the landscape.

SCARCELY VEGETATED SCREE. This subclass is composed of more or less unstable, steep slopes of stones beneath weathering rocks. It grades into prostrate dwarf shrub tundra.

SCARCELY VEGETATED FLOODPLAIN. This subclass is a result of the initial invasion of plants into recent river alluvium. Species colonizing these areas are *Populus balsamifera, Salix alaxensis, Epilobium angustifolium, E. latifolium, Artemisia tilesii, Achillea sibirica, Equisetum arvense, Arenaria physodes* and several members of the Gramineae. Less vegetated areas consisting of alluvium and including silt, sand, and rocks are also included.

Water

Two water subclasses are distinguished, based on water clarity. They range from clear (no sediment load) to turbid. The water class includes lakes, ponds, and rivers. Lakes and ponds are relatively shallow (1-2 m) and support aquatic forbs. These forb formations are dominated by rooted plants such as *Nuphar polysepalum, Isoetes echinospora*, and taxa of the genera *Potamogeton* and *Sparganium*.

CLEAR WATER. This water subclass contains little particulate matter.

TURBID WATER. These water bodies contain visible sediment.

Other Areas

MOUNTAIN SHADOW. Shadows in mountainous or hilly areas make up this class.

Patterns

Vegetation zonation is shown in relation to a vertical topographic gradient in Figure 3. The highest mountains support alpine prostrate dwarf shrub tundra on their rounded tops. These communities are most exposed to wind and are relatively snow free in winter. Erect dwarf shrub tundra occurs at lower elevations than prostrate dwarf shrub tundra, and is more mesic, is less exposed, and retains snow for a longer period than prostrate dwarf shrub tundra. On wind-protected upper slopes a narrow subalpine zone of *Alnus* scrub may develop below the erect dwarf shrub tundra.

Mixed or deciduous forest form on upper and mid-montane slopes, while open black spruce forest and woodlands predominate on the more poorly-drained lower montane slopes and low, rolling hills. Dwarf shrub-graminoid tussock peatlands occur on the

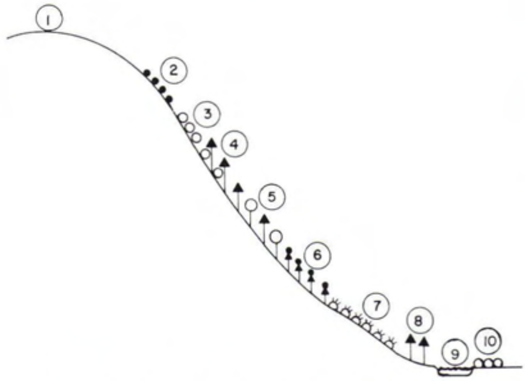

FIG. 3. Schematic profile of a topographic gradient representative of the Nowitna NWR area. Key:

1. Prostrate Dwarf Shrub Tundra (*Dryas octopetala, Salix phlebophylla*)
2. Erect Dwarf Shrub Tundra (*Betula glandulosa, Ledum decumbens, Vaccinium uliginosum*).
3. Subalpine Broadleaf Scrub (*Alnus crispa*).
4. Subalpine Woodland (*Picea glauca - Alnus crispa*).
5. Mixed Forest (*Picea glauca, Betula papyrifera*) or Broadleaf Forest (*Betula papyrifera*).
6. Open Needleleaf Forest or Woodland (*Picea mariana*).
7. Dwarf Shrub - Graminoid Tussock Peatland (*Ledum, Eriophorum*).
8. Alluvial Mixed Forest (*Picea glauca, Betula papyrifera*).
9. River
10. Alluvial Scrub (*Salix*).

bottom portion of lower slopes which are the most poorly drained.

The most productive forests are those associated with river flooding, particularly alluvial *Picea glauca* and *Populus balsamifera* forests. Forests removed from the influence of periodic flooding and associated nutrient enrichment are lower in productivity with trees widely spaced, i.e., woodlands. Lower woodlands grade into *Betula glandulosa - Ledum decumbens* peatlands on wetlands. Wet meander scars or oxbows support graminoid marshes, while *Calamagrostis canadensis* meadows develop on relatively drier scars.

DISCUSSION AND CONCLUSIONS

The Landsat-derived vegetation map is the first intermediate-scale map published for the Nowitna NWR. As such, it is a pioneering effort and the first attempt to map the vegetation in a quantitative and systematic manner. The study increases the number of mapped vegetation classes in the Nowitna NWR from five (Küchler, 1966) to thirteen. Information on vegetation composition extends knowledge of the North American boreal zone.

The use of ancillary data, such as elevation, facilitated our ability to extend the vegetation classification and assisted in establishing ecologically meaningful units. Winter MSS data were helpful in reducing misclassification between treeless wetlands and conferous forests. Accuracy of future Landsat studies in the boreal forest may also be improved by using winter MSS data in a masking procedure.

A goal of comprehensive conservation planning following vegetation map production was to delineate wildlife habitat type. This was accomplished using the classified Landsat MSS data in conjunction with DEM terrain classes following the approach of Bailey (1984). Our discussions with planners and refuge personnel indicate that the habitat maps are useful, flexible, and crucial for conservation planning.

ACKNOWLEDGMENTS

We are grateful to the following taxonomists who identified or confirmed voucher specimens: W.C. Steere (bryophytes), R.E. Andrus (*Sphagnum*), W.W. Mitchell (Gramineae), G.W. Argus (*Salix*), J.H. Hudson (Cyperaceae), and S.L. Welsh (miscellaneous vascular plants). Thanks are extended to J.R. Fisher, Refuge Manager, and T.M. Patton, Assistant Refuge Manager, Nowitna NWR for sharing their field knowledge and logistical support.

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(Received and accepted 3 March 1986)

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