Intermediate-Scale Vegetation Mapping of Innoko National Wildlife Refuge, Alaska Using Landsat MSS Digital Data

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ABSTRACT: A Landsat-derived vegetation map was prepared for Innoko National Wildlife Refuge. The refuge lies within the northern boreal subzone of northwestern central Alaska. Six major vegetation classes and 21 subclasses were recognized: forest (closed needleleaf, open needleleaf, needleleaf woodland, mixed, and broadleaf); broadleaf scrub (lowland, upland burn regeneration, subalpine); dwarf scrub (prostrate dwarf shrub tundra, erect dwarf shrub heath, dwarf shrub-graminoid peatland, dwarf shrub-graminoid tussock peatland, dwarf shrub raised bog with scattered trees, dwarf shrub-graminoid marsh); herbaceous (graminoid bog, graminoid marsh, graminoid tussock-dwarf shrub peatland); scarcely vegetated areas (scarcely vegetated scree and floodplain); and water (clear, sedimented). The methodology employed a cluster-block technique. Sample areas were described based on a combination of helicopter-ground survey, aerial photo-interpretation, 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 1:250,000-scale vegetation map representative of distinctive regional patterns and suitable for use in comprehensive conservation planning.

INTRODUCTION

As PART OF comprehensive conservation planning under the Alaska National Interest Lands Conservation Act of 1980, the U.S. Fish and Wildlife Service was required to identify and describe the wildlife habitats of Innoko National Wildlife Refuge (NWR). Because vegetation is an essential component of habitat, vegetation maps were necessary (Egler, 1977).

Vegetation data suitable for conservation planning for Innoko NWR was scarce. Vegetation of the refuge is known primarily from scattered accounts such as Drury (1956) for the upper Kuskokwim and Buckley and Libby (1957) for a portion of Interior Alaska. Published vegetation maps that included the refuge, for example, Küchler (1966; scale 1:7,500,000), were too broad to impart information appropriate for planning. Accordingly, a new intermediate-scale (1:250,000) vegetation map was needed and a Landsat-derived map was selected as the most practical approach. The major reasons for choosing Landsat were (1) short completion time, (2) remoteness and relatively large area, (3) incomplete availability of aerial photographs, and (4) ease of data base registration and manipulation.

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

GEOGRAPHICAL SETTING

The study area is Innoko NWR (1.5 million ha) located in northwestern central Alaska. It encompasses two land resource areas: Interior Alaska Lowlands (Koyukuk-Innoko subclass) and the Kuskokwim Highlands (Rieger *et al.*, 1979). Soil development occurs on three main surficial types: fluvial, alluvial, and colluvial (Karlstrom *et al.*, 1964). Three soil orders are represented: Inceptisols, Histosols, and Entisols. The most extensive soil subgroups are Histic Pergelic Cryaquepts, Typic Cryochrepts, Pergelic Cryofibrists, and Typic Cryofluvents (Reiger *et al.*, 1979).

The study area is situated in the northern boreal subzone (Hämet-Ahti, 1976). The climate is transitional between maritime and continental (National Oceanic and Atmospheric Administration, 1982). The mean annual temperature and precipitation for Galena (located approximately 80 km north of the study area) are $-4.7°C$ and 330 mm.

The 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 relatively similar. The Commission recognized classes for the refuge as (1) bottomland spruce - poplar forest, (2) upland spruce - hardwood forest, (3) lowland spruce - hardwood forest, (4) lowbrush, muskeg; bog, and (5) alpine tundra.

METHODS

A stepwise procedure was used to develop the vegetation map.

SAMPLING AREA SELECTION

Two cloud-free Landsat multispectral scanner (MSS) scenes (#22410-21144 and -21151, August 1981) that showed the entire refuge were acquired prior to beginning the field investigation. Fourteen sampling areas or training blocks, each 11 by 11 km, were selected from the scenes within by visually interpreting the Landsat images and locating the blocks in areas that represented the total range of spectral variation (Figure 1). Other criteria for training block selection included differences in landforms, soils, vegetation, surficial geology, spatial distribution, and the availability of color-infrared aerial photographs (scale 1:60,000). Stereotriplet color-infrared photographs were obtained for each training block to delineate spectrally homogeneous areas or polygons.

FIELD INVENTORY

In a combined helicopter-ground survey vegetation was description at two levels: general and detailed. At the general

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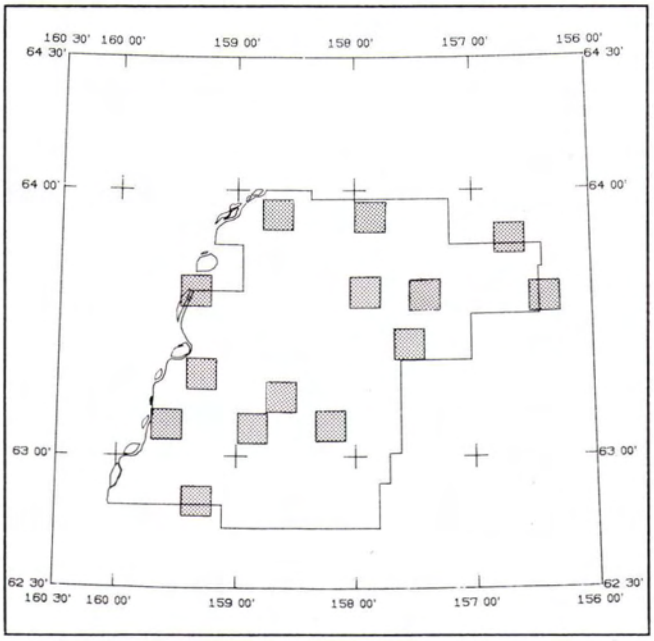

FIG. 1. Map of Innoko National Wildlife Refuge showing training block locations.

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. If a polygon encompassed more than one community type, as in a string bog, each type was described individually. Sampling intensity ranged from 10 to 29 polygons per block. At the detailed level, quantitative descriptions were undertaken to record the floristic composition, structure, and major site features of stands selected to represent the spectrum of major environmental and vegetational variation. To be acceptable for sampling, a stand had to be homogeneous and representative of the community from which it was sampled. Stand descriptions were made from single plots and employed a 10- by 10-m quadrat for nonforest vegetation and 20- by 20-m quadrat for forest vegetation. Quantitative cover values were estimated for each species for nine cover-abundance classes (Westhoff and Maarel, 1973). Qualitative data (presence-absence) were recorded from some stands.

DIGITAL DATA PREPROCESSING

The August, 1981 Landsat scenes were obtained in computer-compatible tape format, and analysis was initiated by selecting a subsection of the scenes that covered the refuge and adjacent lands. 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. Related data sets such as winter Landsat MSS digital data (WMSS), digital terrain data, and refuge boundary data were also registered to the same UTM projection. For scene registration, two ground control points were selected on each USGS topographic map (scale 1:63,360) and the corresponding points on the Landsat scene were located by viewing the image on a color display monitor. These points were used to estimate a second-order, least-squares polynomial transformation equation relating UTM northing and easting values to row and column locations within the Landsat scene. These transformation coefficients rectified the Landsat scenes to a 50-m UTM grid. Examinations of mean residual errors associated with the transformation equation indicated a registration accuracy of less than one pixel (picture element). The final registered Landsat image was 4,200 lines by 4,700 columns in size.

SPECTRAL CLASS DEVELOPMENT

Training classes were developed using a cluster-block approach (Fleming, 1975). A clustering algorithm (ISOCLS) was used to define discrete groups of pixels (clusters) on the basis of their spectral reflectance in the four Landsat spectral bands. The 14 sample blocks were divided into three sets of four blocks and one set of two blocks. Each set of blocks was then grouped using ISOCLS into a specified maximum of 20 spectral classes for a total of 80. The algorithm grouped pixels of similar reflectance values, maximized statistical distance between classes of dissimilar pixels, and provided statistical estimates (mean vector and covariance matrix) for each spectral class. Generating two sets of statistics provided two independent estimates of the spectral properties in the Landsat data. The four files were then merged into one statistical file of 47 spectral classes.

FIELD DATA PROCESSING

A descriptive summary of each vegetation polygon visited in the field was entered into the Earth Resource Information System (ERIS), a subcomponent of IDIMS. The ERIS is primarily a data base system for storing and manipulating tabular data and for performing statistical analyses. The descriptive summary for each site included (1) life form (e.g., forest, scrub, and dwarf scrub), (2) vegetation subclass (preliminary assignment into one of 21 subclasses, for example needleleaf woodland, graminoid bog), (3) topographic information (slope, elevation, and aspect), and (4) polygon alphanumeric label.

To define strata within the digital ancillary data files (WMSS, elevation, slope, and aspect), the field descriptive summary data were compared to the ancillary data within ERIS. We used the IDIMS display monitor to delineate the boundaries of the polygons visited in the field as training sites on the summer Landsat MSS data. The IDIMS creates an image mask that stores the boundary coordinates, allowing them to be transferred to the other registered data sets. Another IDIMS algorithm extracts information from the pixels within these polygons and writes out an ERIS file where each pixel is represented as a case containing its numerical value and polygon label. The label is used to relate the field data to the image-related data and construct a single multivariate data file. The file provides the information necessary to develop strata for post-classification refinement.

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. The process of labeling spectral classes was accomplished primarily through analysis of the ERIS files. Each spectral class was given a preliminary label as determined by the vegetation type most frequently occurring within the spectral class based on the statistical and visual analysis. Inconsistencies in class composition were documented for later refinement in the post-classification phase.

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 the 14 training blocks was applied outside the blocks to the entire two-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 for 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. Innoko 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 (Scene ID 30723-21144 and -21150; 26 February 1980) – 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 mountains' 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. 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 forest communities.

RESULTS

Six major classes and 21 subclasses were distinguished on the Landsat-derived vegetation map. In our paper the vegetation classes are presented as a generalized map produced by resampling the 50-m^2 pixel classification to a 400-m^2 classification (Plate 1). The detailed map is available in color (scale 1:250,000) from the EROS Field Office at the cost of color reproduction. 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. Forest also includes secondary tree growth temporarily less than 5 m in height, i.e, intermediate successional stages. The forest class is the second most abundant class, covering 38.5 percent of the refuge (Table 1). Five subclasses are distinguished:

Closed needleleaf forest. This subclass is characterized by needleleaf tree canopy cover that varies from 50 to 100 percent. The predominant forest species are white spruce (*Picea glauca*) and black spruce (*Picea mariana*).

Picea glauca forests achieve their best development on alluvial sites where they are distinguished by their high growth rates. Trees usually range from 20 to 30 m tall and average 30-cm diameter breast high (dbh). The understory characterized by deciduous shrubs (*Alnus crispa, Rosa acicularis,* and *Viburnum edule*), dwarf shrub (*Linnaea borealis*), forbs (*Equisetum arvense, Mertensia paniculata, Cornus canadensis, Valeriana sitchensis*), graminoids (*Calamagrostis canadensis*), mosses (*Rhytidiadelphus triquetrus, Climacium dendroides,* and *Hylocomium splendens*).

Picea mariana forests occur on imperfectly to poorly drained sites. Trees are lower in stature, ranging from 5 to 10 m, and smaller in girth, averaging 10-cm dbh, than the preceeding type. Characteristic understory species are shrubs (*Ledum groenlandicum, Betula glandulosa,* and *Spiraea beauverdiana*), dwarf shrubs (*Vaccinium uliginosum, V. vitis-idaea*), forbs (*Equisetum sylvaticum, Rubus chamaemorus, Geocaulon lividum*), mosses (*Sphagnum* spp., *Pleurozium schreberi*), and lichens (*Nephroma arcticum*).

Open needleleaf forest. This subclass is characterized by needleleaf tree canopy cover ranging from 20 to 50 percent. Open needleleaf forest predominates on moderately to poorly drained sites that often occur on middle to lower slopes. They are typically dominated by black spruce (*Picea mariana*). Trees range from 5-10 m in height and average 9-cm dbh. Characteristic understory species are shrubs (*Spiraea beauverdiana, Betula glandulosa*), dwarf shrubs (*Ledum decumbens, Vaccinium vitis-idaea, Empetrum nigrum, Oxycoccus microcarpus*), forbs (*Geocaulon lividum, Rubus chamaemorus,* and *Equisetum sylvaticum*), mosses (*Pleurozium schreberi, Sphagnum* spp., and *Polytrichum* spp.), and lichens (*Nephroma arcticum*).

Needleleaf woodland. This subclass is formed of needleleaf trees at least 5 m tall with their crowns very widely spaced. Tree cover ranges from 10 to 25 percent. Needleleaf woodland is primarily dominated by the needleleaf evergreen species, *Picea mariana*, but some communities of the needleleaf deciduous species, *Larix laricina*, also occur.

Picea mariana woodland occurs on poorly drained lower slopes and level peatlands – transition bogs and raised bogs. Trees are stunted and about 5 m tall with an average dbh of 6 cm. Characteristic species are shrubs (*Betula glandulosa, Salix* spp.), dwarf shrubs (*Ledum decumbens, Vaccinium uliginosum, V. vitis-idaea, Empetrum nigrum, Chamaedaphne calyculata, Oxycoccus microcarpos*), forbs (*Rubus chamaemorus, Drosera rotundifolia*), graminoids (*Eriophorum vaginatum, Carex bigelowii*), mosses (*Pleurozium schreberi, Sphagnum* spp.), and lichens (*Cladina alpestris, C. mitis* x *arbuscula, C. rangiferina,* and *Cetraria cucullata*).

Larix laricina swamps usually occur in slightly wetter sites than *Picea mariana* peatlands but tree height and dbh are relatively similar. Characteristic understory species are shrubs (*Betula glandulosa, Alnus incana, Vaccinium uliginosum*), dwarf shrubs (*Salix fuscescens, Myrica gale, Chamaedaphne calyculata*), forbs (*Potentilla

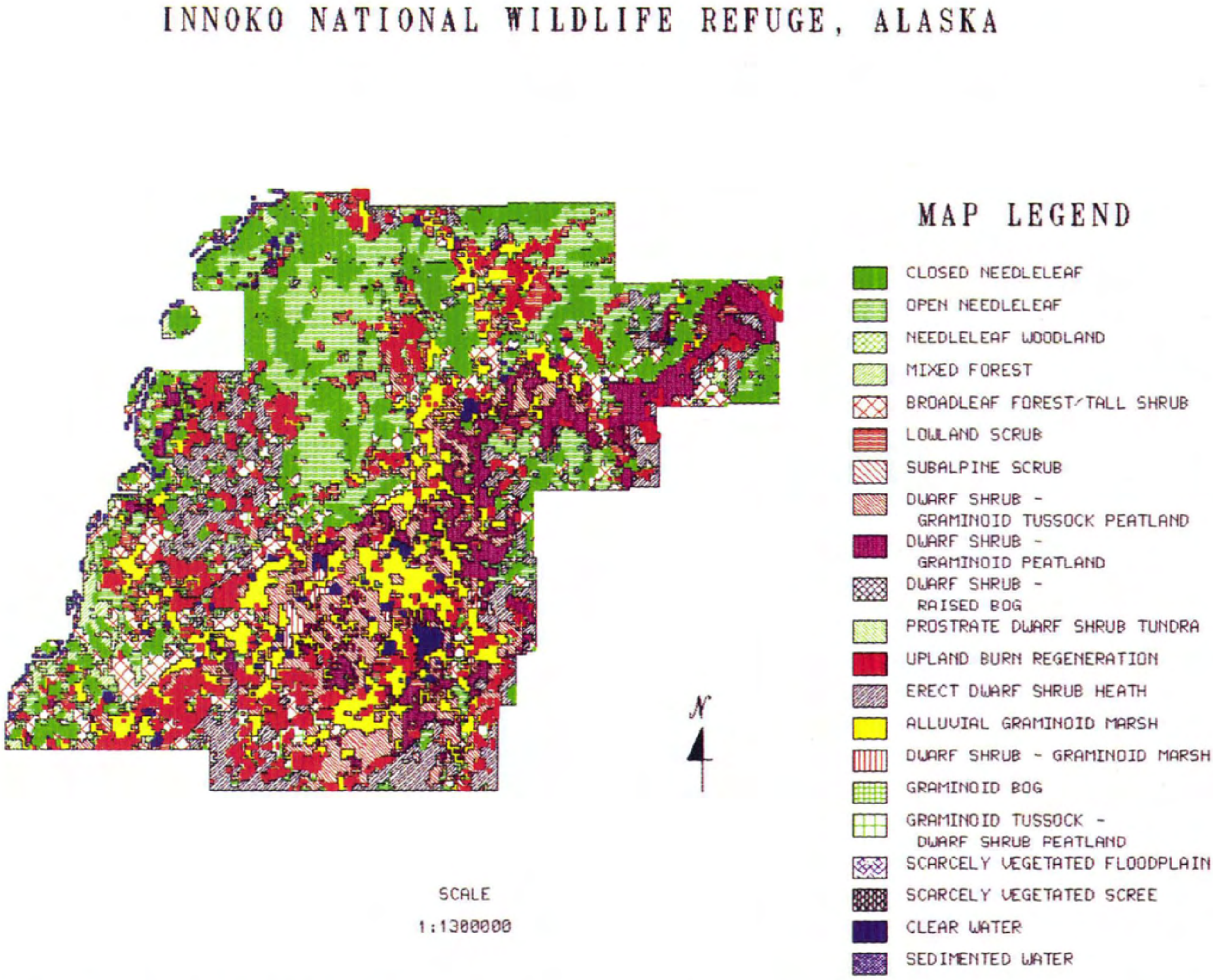

PLATE 1. Generalized map of vegetation subclasses produced by resampling the 50-m^2 pixel vegetation classification to a generalized 400-m^2 pixel classification.

palustris), graminoids (*Calamagrostis canadensis*), and mosses (*Sphagnum* spp., *Hylocomium splendens*).

Mixed forest. Formed by a mixture of deciduous broadleaf (*Betula papyrifera*) and evergreen needleleaf (*Picea glauca*) trees with 25 to 100 percent cover, this subclass covers large areas of well to moderately well drained slopes on mineral soils. Trees are usually 10 to 20 m tall and average about 15-cm dbh. Characteristic understory species are shrubs (*Alnus crispa, Rosa acicularis, Ribes triste,* and *Spiraea beauverdiana*), dwarf shrubs (*Linnaea borealis, Vaccinium vitis-idaea*), forbs (*Cornus canadensis, Equisetum sylvaticum*), graminoids (*Calamagrostis canadensis*), mosses (*Hylocomium splendens, Dicranum fuscescens,* and *Polytrichum* spp.), and lichens (*Peltigera aphthosa*).

Broadleaf forest. This subclass is characterized by broadleaf deciduous trees with 25 to 100 percent cover. The majority of trees shed their foliage in connection with winter frost. Broadleaf forest occurs on mineral soils that are well to imperfectly drained. The primary tree species is white birch (*Betula papyrifera*) occurring on both hillsides and alluvial sites; a secondary species balsam poplar (*Populus balsamifera*) is restricted to alluvial sites; and aspen (*Populus tremuloides*) occurs in minor amounts on upland sites.

Alluvial broadleaf forests dominated by either *Betula papyrifera* or *Populus balsamifera* range in height from 10 to 20 m and average 23-cm dbh. Characteristic understory species are shrubs (*Alnus crispa, Viburnum edule, Cornus stolonifera, Ribes triste, Rosa acicularis,* and *Salix alaxensis*), forbs (*Equisetum arvense, Galium boreale,* and *Rubus arcticus*), graminoids (*Calamagrostis canadensis*), and mosses (*Brachythecium* spp.).

Betula papyrifera forests occur on middle to lower slopes on hillsides and in the mountains. Tree height ranges from 5 to 20 m and dbh ranges from 13 to 26 cm. Characteristic species are trees (*Betula papyrifera, Picea glauca*), shrubs (*Alnus crispa, Spiraea beauverdiana, Ribes triste, Salix bebbiana*), dwarf shrubs (*Vaccinium vitis-idaea*), forbs (*Cornus canadensis, Lycopodium annotinum, Equisetum sylvaticum*), graminoids (*Calamagrostis canadensis*), and mosses (*Dicranum fuscescens, Hylocomium splendens,* and *Polytrichum* spp.).

BROADLEAF SCRUB

This vegetation class is comprised of woody plants 0.5 to 5 m tall that shed their foliage simultaneously in winter. Included in the class are multiple-stemmed woody plants such as alder *Alnus* and willow *Salix,* and single-stemmed tree species like *Betula papyrifera*. Scrub occurs primarily along water courses, poorly drained sites, and in the alpine and subalpine zones. Three subclasses were distinguished:

Lowland scrub. This subclass is associated with alluvial sites and peatlands. Alluvial scrub that occurs along large rivers are

TABLE 1. RELATIVE ABUNDANCE OF VEGETATION SUBCLASSES WITHIN INNOKO NATIONAL WILDLIFE REFUGE.

Vegetation Class	Surface Area Hectares	Surface Area Percent
FOREST		
Closed Needleleaf	128,965.8	8.3
Open Needleleaf	208,828.5	13.6
Needleleaf Woodland	36,120.9	2.3
Mixed	67,920.2	4.4
Broadleaf	151,028.1	9.9
SCRUB		
Lowland	98,991.3	6.5
Subalpine	1,764.9	0.1
Upland Burn Regeneration	118,105.9	7.6
DWARF SCRUB		
Prostrate Dwarf Shrub Tundra	28.2	0.0
Erect Dwarf Shrub Heath	166.0	0.0
Dwarf Shrub - Graminoid Peatland	141,770.2	9.2
Dwarf Shrub - Graminoid Tussock Peatland	144,331.6	9.3
Dwarf Shrub Raised Bog	129,124.0	8.4
Dwarf Shrub - Graminoid Marsh	182,392.0	11.8
HERBACEOUS		
Graminoid Bog	8,212.2	0.5
Graminoid Marsh	25,732.8	1.7
Graminoid Tussock - Dwarf Shrub Peatland	50,266.9	3.2
SCARCELY VEGETATED		
Scree	148.5	0.0
Floodplain	377.0	0.0
WATER		
Clear	48,528.4	3.1
Sedimented	2,033.9	0.1
Total	1,544,837.5	100.0

frequently flooded and silt is deposited. The woody shrubs are often very tall, 5 to 10 m, and outside the normal range of shrub height. The plant species diversity is relatively low. Characteristic species are shrubs (*Salix alaxensis*) and forbs (*Equisetum arvense, Artemisia tilesii, Impatiens noli-tangere,* and *Mentha arvensis*).

On alluvial sites that flood less frequently with little silt accumulation and along streamsides, a riparian scrub develops that is lower in stature, 0.5 to 4 m tall, and with a different composition than the type above. Characteristic species are shrubs (*Salix planifolia* ssp. *pulchra, Alnus incana, Vaccinium uliginosum, Betula glandulosa,* and *Myrica gale*), graminiods (*Carex aquatilis, Calamagrostis canadensis*), and mosses (*Sphagnum* spp.).

Subalpine scrub. This subclass occurs above timberline and is dominated by alder *Alnus crispa*. It peaks in abundance on steep well-drained protected sites in the mountains. Characteristic species are shrubs (*Alnus crispa, Spiraea beauverdiana,* and *Ribes triste*), dwarf shrubs (*Linnaea borealis, Vaccinium vitis-idaea*), forbs (*Dryopteris austriaca, Epilobium angustifolium, Lycopodium annotinum*), and mosses (*Polytrichum commune*).

Upland burn regeneration. This subclass is associated with post-fire regeneration. Floristic composition varies because secondary succession can follow an array of sequences following fire. However, several species are often present or achieve high abundance in the initial post-fire regeneration: *Epilobium angustifolium, Calamagrostis canadensis, Populus tremuloides, Betula papyrifera, Ledum decumbens, Betula glandulosa, Alnus crispa,* and *Polytrichum* spp.

DWARF SCRUB AND RELATED TYPES

This vegetation class is composed of slow growing dwarf shrubs less than 0.5 m, composed chiefly of Ericaceae and Empetraceae. An abundance of mosses and lichens grow amidst the dwarf shrubs. Within the class, six subclasses are recognized:

Prostrate dwarf shrub tundra. The term "tundra" is often used with very different meanings, but as used here it refers to low growing vegetation above the limit of continuous forests in the mountains. This subclass is composed of relatively bare, alpine communities and includes fellfields. These communities are exposed to wind and are relatively snow free in winter. Characteristic species are dwarf shrubs (*Dryas octopetala, Empetrum nigrum, Salix phlebophylla, S. arctica, Vaccinium vitis-idaea, Loiseleuria procumbens, Diapensia lapponica,* and *Arctostaphylos alpina,* forbs (*Antennaria alpina, Dryopteris fragrans, Oxytropis nigrescens, Artemisia arctica, Potentilla villosa, Podistera macounii, Cerastium fischerianum,* and *Campanula lasiocarpa*), graminoids (*Hierochloë alpina, Tofieldia coccinea, Luzula wahlenbergii,* and *L. nivalis*), mosses (*Rhytidium rugosum, Racomitrium lanuginosum, Dicranum elongatum,* and *Polytrichum piliferum*), and lichens (*Cetraria cucullata, C. nivalis, Sphaerophorus globosus,* and *Alectoria ochroleuca*).

Erect dwarf shrub heath. This subclass occurs below prostrate dwarf shrub tundra or on lower elevation hilltops. Accordingly, the (1) plant cover is more closed, (2) soils are more mesic, and (3) woody shrubs are more erect than the former. Characteristic species are shrubs and dwarf shrubs (*Betula glandulosa, Ledum decumbens, Vaccinium uliginosum, V. vitis-idaea, Salix scouleriana,* and *Empetrum nigrum*), graminoids (*Carex bigelowii*), mosses (*Dicranum elongatum, Pleurozium schreberi, Hylocomium splendens, Sphagnum fuscum,* and *Sphagnum russowii*), and lichens (*Cladina alpestris, C. mitis, C. mitis* × *arbuscula, Nephroma arcticum, Peltigera aphthosa,* and *Cetraria cucullata*).

Dwarf shrub-graminoid peatland. Peatland refers to organic terrain covered by peat approximately 30 cm in depth or greater. This peatland subclass occurs on very poorly drained sites on nearly level terrain in the lowlands. When seen from the air, the peatland surface often exhibits a pattern of organic ridges and hollows. The ridges are typically dominated by dwarf shrubs and the hollows by graminoids. Most patterned areas are relatively nutrient poor but some nutrient rich areas occur. Characteristic species of nutrient poor hummocks are trees (*Picea mariana*), shrubs and dwarf shrubs (*Betula glandulosa, Andromeda polifolia, Ledum decumbens, Vaccinium uliginosum, V. vitis-idaea*), forbs (*Rubus chamaemorus, Drosera rotundifolia*), graminoids (*Eriophorum vaginatum*), mosses (*Sphagnum fuscum, S. balticum, S. rubellum*), and lichens (*Cladina alpestris, C. rangiferina, C. mitis* × *arbuscula, Cetraria cucullata*, and *C. nivalis*), while hollows are typified by dwarf shrubs (*Andromeda polifolia, Oxycoccus microcarpus*), forbs (*Drosera anglica*), graminoids (*Eriophorum scheuchzeri, Carex membranacea*, and *C. limosa*), and mosses (*Sphagnum riparium, S. balticum*). The hummocks of nutrient-rich patterned fens are characterized by trees (*Larix laricina*), shrubs and dwarf shrubs (*Myrica gale, Andromeda polifolia, Chamaedaphne calyculata, Betula glandulosa*, and *Potentilla fruticosa*), forbs (*Equisetum fluviatile, Parnassia palustris*), graminoids (*Carex limosa, C. loliacea, Calamagrostis canadensis*, and *Eriophorum scheuchzeri*), and mosses (*Campylium stellatum, Hypnum lindbergii*), while the hollows are typified by forbs (*Equisetum fluviatile, Menyanthes trifoliata*), graminoids (*Carex limosa, C. rostrata*, and *C. chordorrhiza*), and mosses (*Scorpidium scorpioides*).

Dwarf shrub — graminoid tussock peatland. This peatland subclass predominates on lower slopes of hillsides and mountains. The soils are poorly drained. Dwarf shrubs and graminoid tussocks are abundant. Characteristic species are dwarf shrubs (*Ledum decumbens, Empetrum nigrum, Vaccinium uliginosum, V. vitis-idaea, Betula glandulosa*, and *Oxycoccus microcarpus*), forbs (*Rubus chamaemorus, Drosera rotundifolia*), graminoids (*Eriophorum vaginatum, Carex bigelowii*), mosses (*Sphagnum fuscum, S. balticum*, and *Dicranum elongatum*), and lichens (*Cladina alpestris, C. rangiferina, C. mitis* × *arbuscula*, and *Cetraria cucullata*).

Dwarf shrub raised bog with scattered trees. This peatland subclass is composed of raised ombrotrophic peat plateaus and palsen. As peat accumulates by the growth of *Sphagnum* and other species on flat, low-lying areas, a bog is formed whose raised surface prevents the inflow of water from mineral soil. The bogs are dependent on precipitation for water and nutrients. The peat therefore shows low fertility and pH. Characteristic species are trees (*Picea mariana*), dwarf shrubs (*Ledum decumbens, Oxycoccus microcarpus, Vaccinium vitis-idaea, Andromeda polifolia, Betula glandulosa*, and *Empetrum vigrum*), graminoids (*Eriophorum vaginatum*), mosses (*Sphagnum fuscum, S. balticum, Mylia anomala*), and lichens (*Cladina alpestris, C. rangiferina, C. mitis* × *arbuscula, Cetraria cucullata, Icmadophila ericetorum*).

Raised peat plateaus have a pock-marked surface as seen from the air due to pockets of melting ice. Graminoid bogs dominate in these thermokarst depressions. Characteristic species are dwarf shrubs (*Chamaedaphne calyculata, Andromeda polifolia*, and *Oxycoccus microcarpus*), forbs (*Drosera anglica*), graminoids (*Carex membranacea, Eriophorum scheuchzeri*), and mosses (*Sphagnum compactum, S. balticum*).

Dwarf shrub — graminoid marsh. Marshes are wet areas periodically inundated up to 1 m with standing or moving water. The water usually remains within the rooting zone of plants for at least part of the growing season. This wetland subclass is associated with riverine systems that are subject to occasional flooding. Characteristic species are shrubs (*Salix planifolia* ssp. *pulchra, Betula glandulosa*), dwarf shrubs (*Salix fuscescens*), forbs (*Potentilla palustris, Equisetum fluviatile*, and *Rubus arcticus*), graminoids (*Calamagrostis canadensis, Carex aquatilis*, and *C. chordorrhiza*), mosses (*Sphagnum squarrosum, Aulacomnium palustre*).

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 such as *Carex* and *Eriophorum*. Forbs are broad-leaved herbaceous plants such as *Menyanthes* and *Potentilla*. Three herbaceous subclasses were distinguished:

Graminoid marsh. This marsh subclass is typically found in frequently flooded sites along rivers or lake shores. The sites are relatively wetter than the dwarf shrub-graminoid marsh subclass. Characteristic species are dwarf shrubs (*Salix planifolia* ssp. *pulchra, S. fuscescens*), forbs (*Potentilla palustris, Galium trifidum, Menyanthes trifoliata*, and *Equisetum fluviatile*), graminoids (*Calamagrostis canadensis, Carex rostrata*, and *C. aquatilis*), and mosses (*Sphagnum squarrosum*.

Included within the subclass are graminoid meadows. They are also associated with alluvial sites, particularly dried-up oxbow lakes. The silty substrate is usually imperfectly drained. Characteristic species are graminoids (*Calamagrostis canadensis*) and forbs (*Stellaria longipes, Potentilla norvegica*).

Graminoid tussock-dwarf shrub peatland. This subclass is similar to the dwarf shrub-graminoid tussock peatland subclass but there is a shift to greater dominance of graminoid tussocks. Also, this subclass seems to appear more frequently in the alpine zone. The characteristic species are dwarf shrubs (*Betula glandulosa, Vaccinium uliginosum, V. vitis-idaea, Empetrum nigrum* and *Ledum decumbens*), forbs (*Rubus chamaemorus*), graminoids (*Eriophorum vaginatum, Carex bigelowii*), mosses (*Sphagnum lenense, S. russowii, S. balticum, S. fimbriatum*, and *Dicranum* spp.), and lichens (*Cetraria cucullata, Peltigera aphthosa*, and *Cladonia* spp.).

Graminoid bog. Bogs are peat-covered areas with a high water table and a surface cover of mosses, primarily *Sphagnum*. They occur on nearly level areas in the lowlands and their characteristic species are dwarf shrubs (*Chamaedaphne calyculata, Oxycoccus microcarpus, Andromeda polifolia, Betula glandulosa*), forbs (*Menyanthes trifoliata, Drosera rotundifolia, D. anglica*), graminoids (*Carex membranacea, C. aquatilis, C. chordorrhiza, Eriophorum scheuchzeri*), and mosses (*Sphagnum balticum, S. magellanicum, S. papillosum*, and *S. angustifolium*).

Scarcely Vegetated Areas

In this class, plants are scattered or absent, and bare mineral soil or rock determines the overall appearance of the landscape. There are two subclasses:

Scarcely vegetated scree. This subclass is composed of more or less unstable, steep slopes of stones beneath weathering rocks. It grades into fellfield and prostrate dwarf shrub tundra.

Scarcely vegetated floodplain. This subclass is a result of the initial invasion of plants into recent river alluvium. Species that colonize these areas are *Equisetum arvense, Epilobium angustifolium, E. latifolium*, and several members of the Salicaceae, Gramineae, and Leguminosae.

Water

The water class includes water bodies such as lakes, ponds, and rivers. Associated vegetation is composed of rooted fresh water aquatic communities dominated by forbs (*Nuphar polysepalum, Potamogeton* spp.) and graminoids (*Isoetes echinospora, Sparganium* spp.). Two water subclasses are distinguished based on water clarity:

Clear water. This water subclass contain little particulate matter.

Sedimented water. These water bodies, usually rivers, are turbid and contain visible sediment.

DISCUSSION AND CONCLUSIONS

The Landsat-derived vegetation map is the first intermediate-scale map published for the Innoko NWR. As such, it is a pioneering effort for the refuge 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 Innoko NWR from five (Joint Federal-State Planning Commission for Alaska, 1973) to 21. Information on vegetation composition extends knowledge of the North American boreal zone.

Our goal of comprehensive conservation planning was to use vegetation classification to delineate wildlife habitat types. This was accomplished using the classified Landsat MSS data in conjunction with DEM terrain classes, using Bailey's (1984) approach. Our discussions with planners and refuge personnel indicate that the habitat maps are useful, adaptable, and crucial for conservation planning.

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