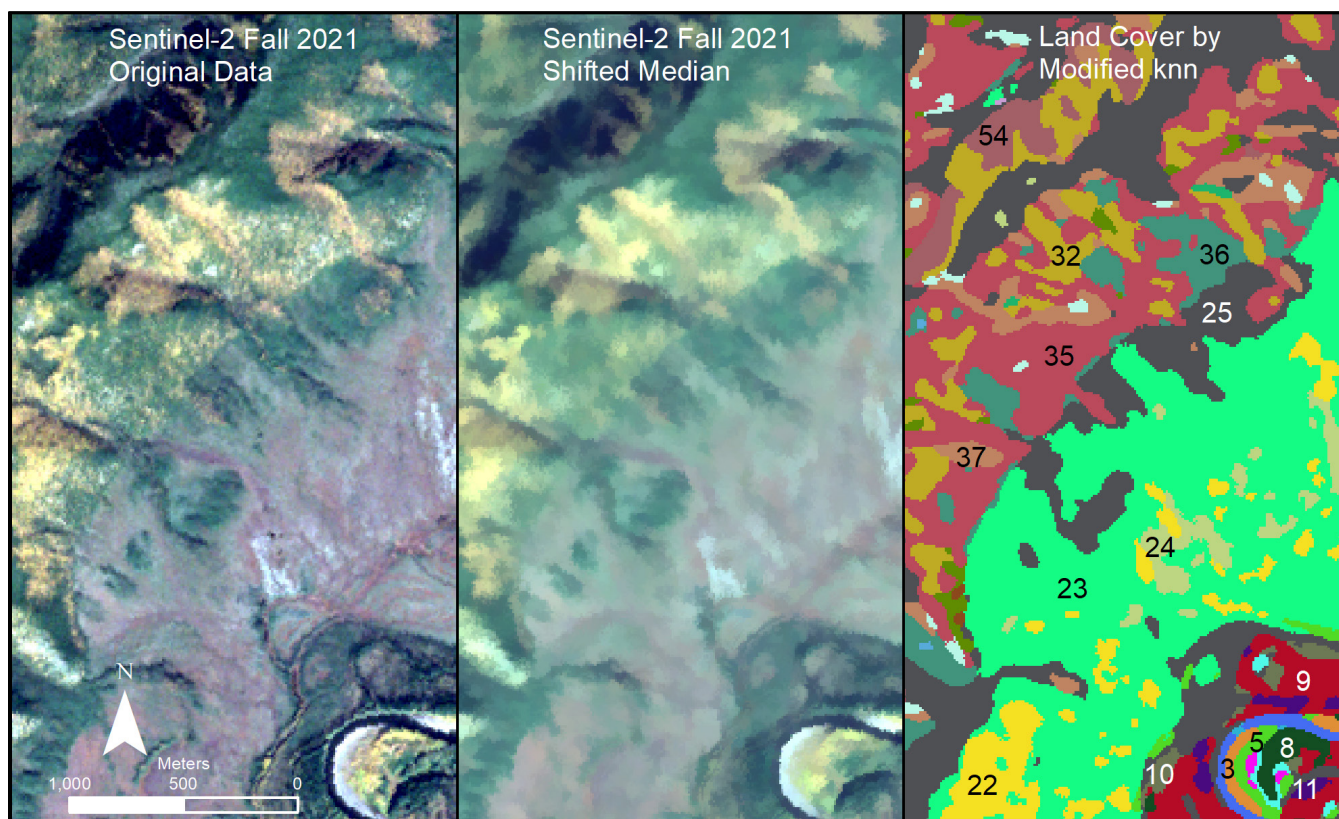




Land Cover Map of Yukon-Charley Rivers National Preserve, 2022

Natural Resource Report NPS/YUCH/NRR—2023/2552



ON THE COVER

Basic steps in the land cover mapping process. On the left, the original fall 2022 Sentinel-2 satellite image. In the center, the Sentinel-2 image after processing with an edge-preserving smoother. On the right, the smoothed image classified by the modified knn method. Numbers refer to land cover types, described in the report. The scene is centered near longitude 142.35°, latitude 65.44°, with the Kandik River visible in the lower right.

NPS

Land Cover Map of Yukon-Charley Rivers National Preserve, 2022

Natural Resource Report NPS/YUCH/NRR—2023/2552

David K. Swanson

¹ National Park Service
4175 Geist Road
Fairbanks, Alaska 99709

August 2023

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible and technically accurate.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from the [Natural Resource Publications Management website](#). If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Please cite this publication as:

Swanson, D. K. 2023. Land cover map of Yukon-Charley Rivers National Preserve, 2022. Natural Resource Report NPS/YUCH/NRR—2023/2552. National Park Service, Fort Collins, Colorado. <https://doi.org/10.36967/2300010>

Contents

	Page
Figures.....	v
Tables.....	vi
Appendices.....	vii
Abstract.....	viii
Acknowledgments.....	ix
List of Terms.....	ix
Introduction.....	1
Project Background	1
Study Area.....	2
Methods.....	3
Imagery.....	3
Sentinel-2 satellite images.....	3
Elevation, Topography, and Vegetation Height.....	8
Image Smoothing.....	9
Legend.....	11
Classification	11
Training data.....	11
Classifier.....	12
Masking.....	14
Class Selection and Final Modal Smoothing.....	14
Training Verification.....	15
Random Forest Classification.....	16
Results.....	17
Comparison with the Previous Map	24
Cover Types, Major Landforms, and Fire.....	26
Training Data Accuracy Check	29

Contents (continued)

	Page
Comparison with Random Forest Classification	34
Discussion	36
Vegetation Condition and Change	36
Smoothing vs. Segmentation	36
Choice of Classifier: Random Forest vs. Modified knn	37
Scale considerations	38
Accuracy	38
Costs and Time	40
Literature Cited	41

Figures

	Page
Figure 1. Location of Yukon-Charley Rivers National Preserve.	1
Figure 2. Summer composite Sentinel-2 satellite image, presented in color-infrared color scheme (green, red, and color-infrared presented as blue, green, and red).	4
Figure 3. Image dates used in the Sentinel-2 summer composite.	5
Figure 4. Fall composite Sentinel-2 satellite image, presented in a true color scheme.	6
Figure 5. Image dates used in the Sentinel-2 fall composite.	7
Figure 6. Smoothing of a fall Sentinel-2 satellite image (left) with the median (center) and shifted median (right).	10
Figure 7. Example Principal Components Analysis plot.	15
Figure 8. Plot of the area per training point vs. the total area occupied by each cover type.	23
Figure 9. Location of historical fire perimeters in relation to mountainous areas and the Yukon River floodplain, as outlined by ecological subsections (Swanson 1999).	27
Figure 10. Comparison of maps produced by the modified knn method (center) and Random Forest (right) with the fall 2021 satellite image (left).	34
Figure D1. Random Forest Variable Importance Plot.	74

Tables

	Page
Table 1. Data elements used in the land cover classification.	3
Table 2. Vegetation plot data sources.	12
Table 3. Land cover type descriptions.....	17
Table 4. Definitions of the vegetation structural terms used in the cover type descriptions.	20
Table 5. Cover type areas, training point counts, and area per point of the types.....	22
Table 6. Area occupied by land cover types from the current and previous land cover maps.	24
Table 7. Area occupied by land cover types in riparian zones from the current and previous land cover maps.....	25
Table 8. Area of land cover types by major landform zones.	28
Table 9. Classification matrix of training points, by the modified knn method—part one.....	30
Table 10. Classification matrix of training points, by the modified knn method—part two.....	32
Table A1. Polygon masks used in land cover type classification.	44
Table C1. Plant associations (Boggs and Sturdy 2005) of the land cover types.....	50
Table C2. USDA-NRCS ecosites of the land cover types.	54
Table C3. US National Vegetation Classification groups of the land cover classes (USNVC 2023).	65
Table C4. The Alaska Vegetation Classification (Vioreck et al. 1992) of the land cover classes.	67
Table C5. Equivalent land cover types in the present study and the previous YUCH land cover map (Ducks Unlimited 2002).....	69
Table C6. Simplified legend options.....	71
Table D1. Random Forest classification matrix—part one.....	75

Appendices

	Page
Appendix A: Additional Classification Data	44
Appendix B: Key to the Land Cover Classes	46
Appendix C: Tables relating the map legend to other classifications	50
Appendix D: Random Forest Classification Results.....	74

Abstract

A land cover map of Yukon-Charley Rivers National Preserve has been produced to replace an outdated map from 1991. The new map is intended for use at a scale of 1:24,000. It is based on Sentinel-2 satellite image data (10-m resolution), plus topographic and vegetation height data from the Alaska Statewide IFSAR digital elevation model (DEM; 5 m resolution, resampled to 10 m). The image data were smoothed using an edge-preserving filter. Training data points were located by examining the Sentinel-2 and higher-resolution image data, and topographic maps while referencing field plot data from multiple different projects: primarily the USDA-NRCS soil survey sample plots and the NPS Central Alaska Inventory and Monitoring Network vegetation monitoring plots. The training points were used to extract training data from the smoothed images, which was then used to classify the smoothed data from the whole study area. Classification was by a modification of the k-nearest neighbor method, and also by Random Forest for comparison. The two methods produced similar results; and the modified knn method appeared to be slightly better and was chosen for the final product. This map was made with minimal cost, thanks to extensive pre-existing vegetation data and free imagery. However, as a result of the reduced expenditure and effort, the map lacks customized vegetation type descriptions and a comprehensive error analysis. Thirty-eight land cover types were mapped, including 31 vegetated types, water, and 6 unvegetated or sparsely vegetated types. Bootstrap analysis using the training data, and overlap analysis of the maps by the two methods, suggest that both had accuracies of greater than 80%, and possibly as high as 90% for the modified knn map.

Comparison with the 1991 map suggests loss of coniferous forest due to fires, especially in the terrace and foothill landforms, and its replacement with shrubs, deciduous forest, and mixed forest. Upland white spruce forest appears to have been reduced in these areas, while lowland black spruce forest and woodland persisted in spite of the fires. Extensive areas of unburned subalpine spruce woodland are still present at higher elevations, where fires are rare. The total vegetated area on the Yukon River floodplain appears to have remained fairly stable since 1991, while the area of coniferous forest on floodplains appears to have decreased.

Acknowledgments

This project would not have been possible without the painstaking work of field personnel through the years who collected the plot data used to train the author's eye to identify land cover types in the study area. Thanks especially to Beth Elliot, Parker Martyn, Nathan Parry, Carl Roland, and Shelli Swanson for making these data available. These various field projects were all funded and supported by the National Park Service at various levels: Yukon-Charley Rivers National Preserve, the Central Alaska Inventory and Monitoring Network, and the national NPS Inventory and Monitoring program. The author's time on this project was funded by the NPS Focused Condition Assessment program, thanks to Kyle Joly, Jeff Rasic, Eric Wald, and Jim Lawler for facilitating this. Thanks also to Parker Martyn, Fleur Nicklen, and Carl Roland for helpful review comments.

List of Terms

Alaska Albers Projection: A map projection and coordinate system used in Alaska where the entire state is projected onto a flat surface and the coordinates are distances measured in meters from an arbitrary point.

Digital Elevation Model (DEM): A raster where the value of each pixel is its elevation.

Filter. As applied to the processing of raster data, the application of a summary function, such as the median, to a neighborhood around each pixel, with the result assigned to the central pixel, while maintaining the resolution of the original raster.

Interferometric Synthetic Aperture Radar (IFSAR): The remote sensing technology used to create the digital elevation and vegetation height data used in this study.

Image Classification: The process of assigning a class (in our case, a land cover class) to each pixel of an image.

K nearest neighbor (knn): A classification method where the difference is computed between test cases (in our application, unknown pixels on images) and a set of training cases with known class. The class of the most similar training value (the nearest neighbor) is assigned to the test case. More than one neighbor may be used, in which case the majority class of k nearest neighbors is assigned to the test case.

Landsat: A series of satellites operated by the United States that orbit the earth and collect reflectance data. Since the 1980s these data have been at 30 m resolution.

Pixel: The single element, usually a square, that composes a raster.

Producer's Accuracy: A measure of map accuracy. A classification method is applied to a set of cases with known class. The number of cases that were correctly identified in each class is divided by the total number of cases known to be of that class. See also *User's Accuracy*.

Random Forest (RF): A classification technique developed by Breiman (2001) that constructs numerous decision trees from subsets of the training data and assigns the class to each test case that was found by the majority of trees.

Raster: Image data stored in the form of a systematic grid of pixels.

Resolution: As applied to rasters, the dimension of the side of a square pixel, i.e., its height or width.

Segmentation: The process of dividing an image into relatively homogenous, separate regions containing multiple pixels. Data may then be summarized for segments, and segments may be classified rather than individual pixels.

Sentinel-2: Two satellites owned by the European Space Agency that cover our study area approximately every 3 days and return reflectance data at 10-m resolution.

Supervised classification: Creation of a thematic map (in our case, a map of land cover) from image data using training data and a quantitative classification method.

Training data: Data taken from known examples of different classes and used to classify unknown parts of an image. In our case, these data are surface reflectance and topographic data.

Universal Transverse Mercator (UTM): A map projection and coordinate system where the curved surface of the earth is projected onto a flat surface and the coordinates are distances measured in meters from an arbitrary origin point. The entire earth is divided into 60 UTM zones, to minimize distortion in any given area. Our study area is covered by UTM zones 06 north and 07 north.

User's Accuracy: A measure of map accuracy. A classification method is applied to a set of cases with known class. The number of cases that were correctly identified in each class is divided by the total number of cases placed in that class by the classifier. This is of interest to users of the map because it estimates how many new points on the map would be correctly classified. See also *Producer's Accuracy*.

Introduction

Project Background

Vegetation is a crucial resource that is integral to numerous other resources and ecosystem services, including wildlife habitat, water quality, permafrost, carbon storage, wildfire behavior, visitor viewsheds, and overall biodiversity. The most basic information about vegetation is provided by maps, and for this reason vegetation mapping was chosen as one of the "Twelve Basic Inventories" of the National Park Service (NPS) Inventory and Monitoring Division (<https://www.nps.gov/im/12-basic-inventories.htm>).

Prior to this project, Yukon-Charley Rivers National Preserve (YUCH, Figure 1) had the oldest vegetation inventory of any NPS unit in Alaska (Ducks Unlimited 2002). This map was based on an August 20, 1991 satellite image and field data collected in 1997. In the 31 years since the 1991 image was collected, 21% of the Preserve has burned in wildfires. Furthermore, another 18% of the Preserve burned in the 30 years prior to the 1991 image and thus has been changing rapidly by plant succession since the time of the previous map. In addition, in the past 31 years riparian vegetation has been affected by erosion, new river bars have been deposited, and plant succession has continued in existing young riparian vegetation. Comparison of old and new images as a part of this study showed that trees have increased in tree-line areas also. These changes have combined to make the previous YUCH land cover map out-of-date.

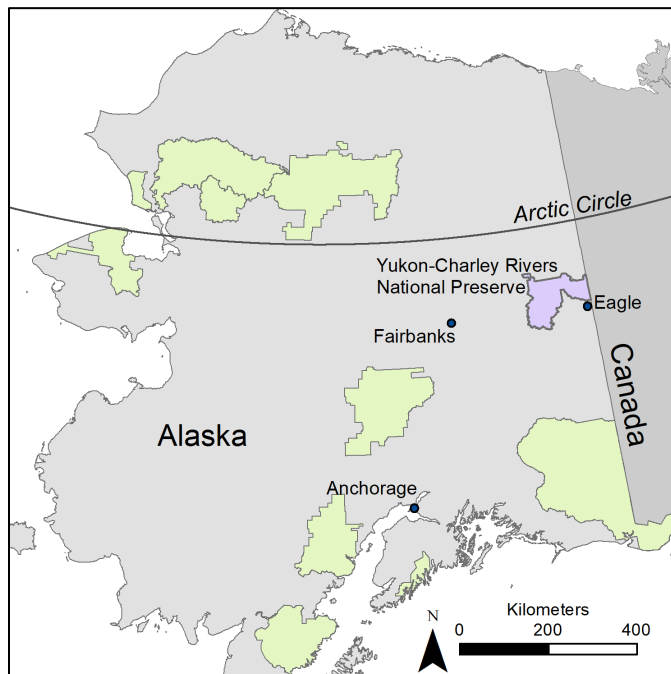


Figure 1. Location of Yukon-Charley Rivers National Preserve. Other NPS units are shown in green.

Fortunately, the data and technology available to support land cover mapping has advanced greatly since the 1990s. To produce the standard vegetation products used nationally by NPS (1:24,000 scale

with 0.5 ha minimum mapping delineation; Cook 2016) from a satellite image requires image resolution of 10 m or finer. The Sentinel-2 satellite provides multispectral satellite images at 10 m resolution free of charge at frequent time intervals for all of Alaska. In addition, since the year 2000 over a thousand vegetation plots have been sampled in YUCH and were available to ground-truth a new mapping effort. Thus the data existed to produce an updated and improved land cover map of YUCH for the cost of analyst time alone. The purpose of this report is to describe the methods and land cover classes used to produce the new land cover map of YUCH, and to make a brief assessment of current conditions and a comparison with the previous YUCH land cover map (Ducks Unlimited 2002).

Study Area

YUCH covers an area of 10,210 km², located in east-central Alaska. While only mid-sized when compared with other Alaskan NPS units, it is larger than all NPS units outside of Alaska except Death Valley National Park. I extended the map to include a 10-km wide buffer zone around the Preserve. The vegetation of neighboring areas is clearly significant to park resources, and I judged 10 km to be a reasonable distance to extrapolate outside the Preserve from our data sources located inside the Preserve (e.g., vegetation plots and high-resolution images); also, a buffer zone of this size did not add a large additional workload. The DEM data used to make the map do not cover all of the 10-km buffer zone outside of the Preserve in Canada, so the final map does not fill the buffer zone completely there.

YUCH is roadless and accessed by water, air, or foot. Elevations range from 180 m (590 ft) along the Yukon River where it exits the Preserve to 1960 m (6435 ft) in the mountains in the upper Charley River region. YUCH has a continental climate, with long cold winters and short warm summers. National Weather Service data (NCEI 2023) from Eagle, Alaska (1981–2010, 260 m elevation, near the eastern boundary of the Preserve) showed a mean annual temperature of -3.3°C , January -22.8°C , July 15.9°C , precipitation 327 mm. Vegetation is boreal forest up to an elevation of about 1070 m (3500 ft), with tundra above. Permafrost is widespread but discontinuous (Jorgenson et al. 2008).

Methods

The map was produced by supervised classification of smoothed satellite-image data. The image sources, smoothing routine, and classifier used are described below. The data layers used in the classification are summarized in Table 1. The training data and R code used to produce the map, and the final map, are stored in the NPS Data Store at

<https://irma.nps.gov/DataStore/Reference/Profile/2297197>. Nearly all raster processing was done using the R package “terra” (Hijmans 2022). I used ArcGIS 10.8.1 to digitize training point locations and mask polygon boundaries, and to project rasters between coordinate systems.

Table 1. Data elements used in the land cover classification.

Source	Data Elements	Description
Sentinel-2 satellite	Summer composite image	Red, green, blue, and near-infrared reflectance
	Fall composite image	Red, green, blue, and near-infrared reflectance
IFSAR DEM	Elevation	Elevation above sea level, m
	Slope	Surface slope in degrees
	Southwestness	Computed from slope steepness and the deviation of slope aspect from southwest; a measure of solar heating
	Illumination index	A measure of illumination and shading on the image. Computed from slope steepness and the deviation of slope aspect from the solar azimuth at the time of the Sentinel-2 flyover (10:30 AM local solar time).
	Curvature	Convexity of the ground surface
	Vegetation height	Difference between “Highest Surface” and “Bare Earth”, in 2015

Imagery

Sentinel-2 satellite images

I used Sentinel-2 data for surface reflectance. This was the Level-1C product (10-m resolution orthorectified Top-Of-Atmosphere reflectance, with sub-pixel multispectral registration) for the blue (band 2), green (band 3), red (band 4), and near-infrared (band 8) spectral bands, in Universal Transverse Mercator (UTM) coordinate system (European Space Agency 2022a). I downloaded these data from the Copernicus Open Access Hub (European Space Agency 2022b) for the 4 tiles needed to cover YUCH with a 10 km buffer outside of the Preserve boundary: tiles 06WXS, 06WXT, 07WDM, and 07WDN.

I created Preserve-wide composite images for the summer (mostly from 11 August 2022; Figures 2 and 3) and fall (mostly from 11 September 2021 and 15 Sept 2019; Figures 4 and 5). To fill in missing or cloudy areas in the main image for each date, I manually clipped out each cloudy area and pieced in an image fragment from the available cloud-free date that most closely matched the date with the missing area. I used linear regression to adjust the colors of the patch to match the matrix (main) image: I chose an area that was cloud-free on both dates near the place needing the patch;

regressed each wavelength band of the patch vs. the matrix, and then used the regression coefficients to adjust the patch to match the matrix. This patching process was completed in the original UTM coordinate system of each tile.

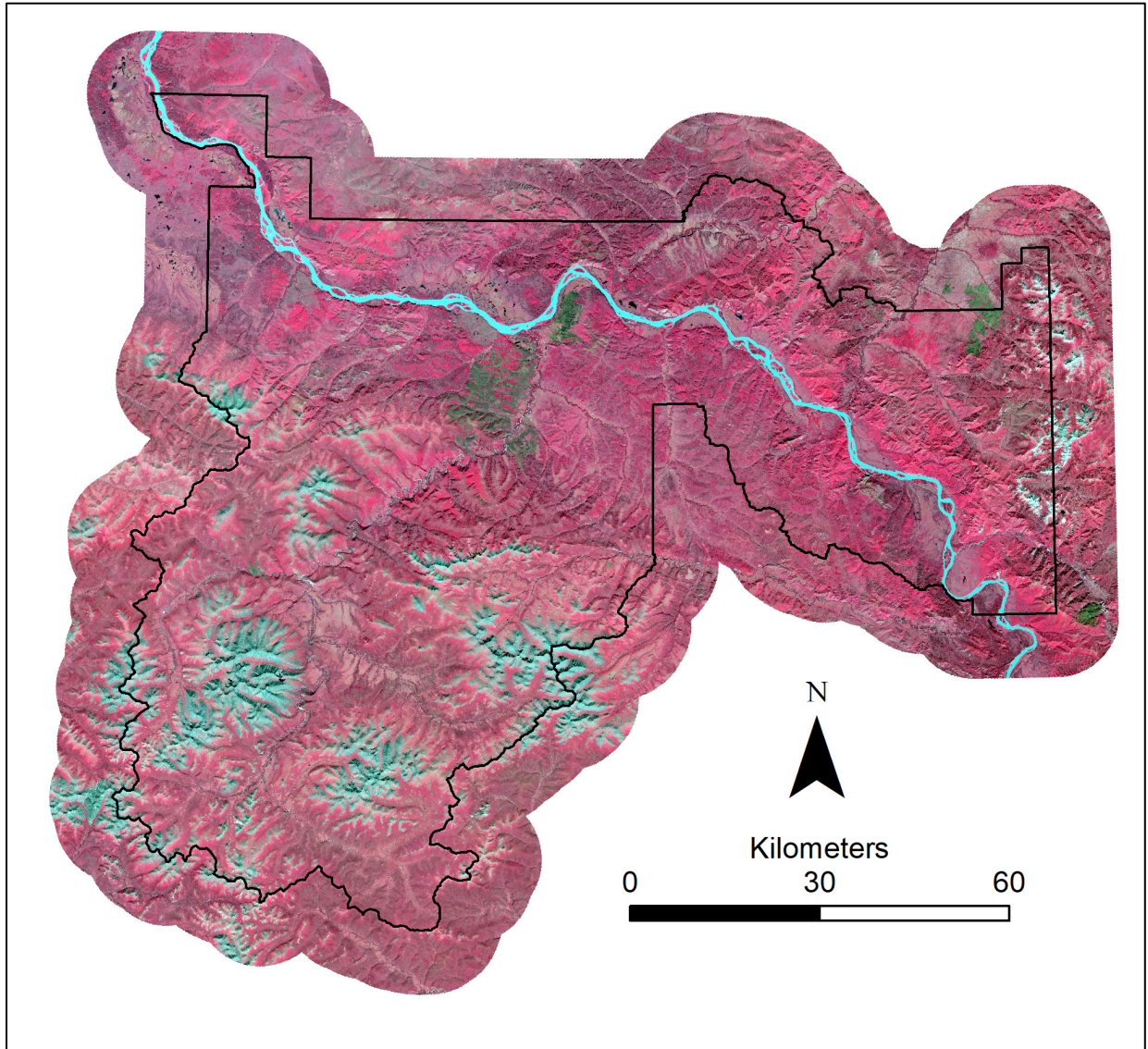


Figure 2. Summer composite Sentinel-2 satellite image, presented in color-infrared color scheme (green, red, and color-infrared presented as blue, green, and red). The outline of YUCH is shown in black.

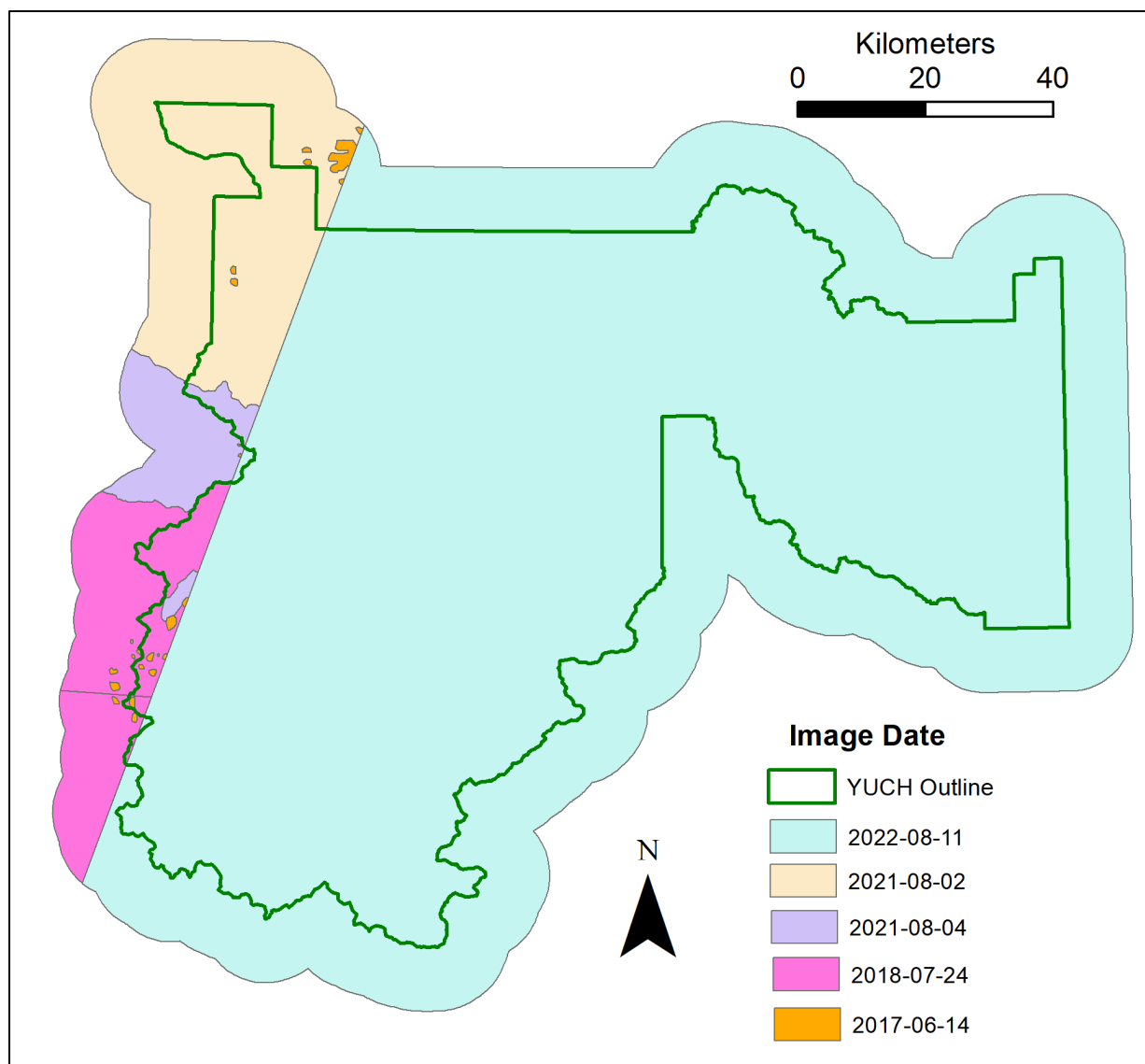


Figure 3. Image dates used in the Sentinel-2 summer composite.

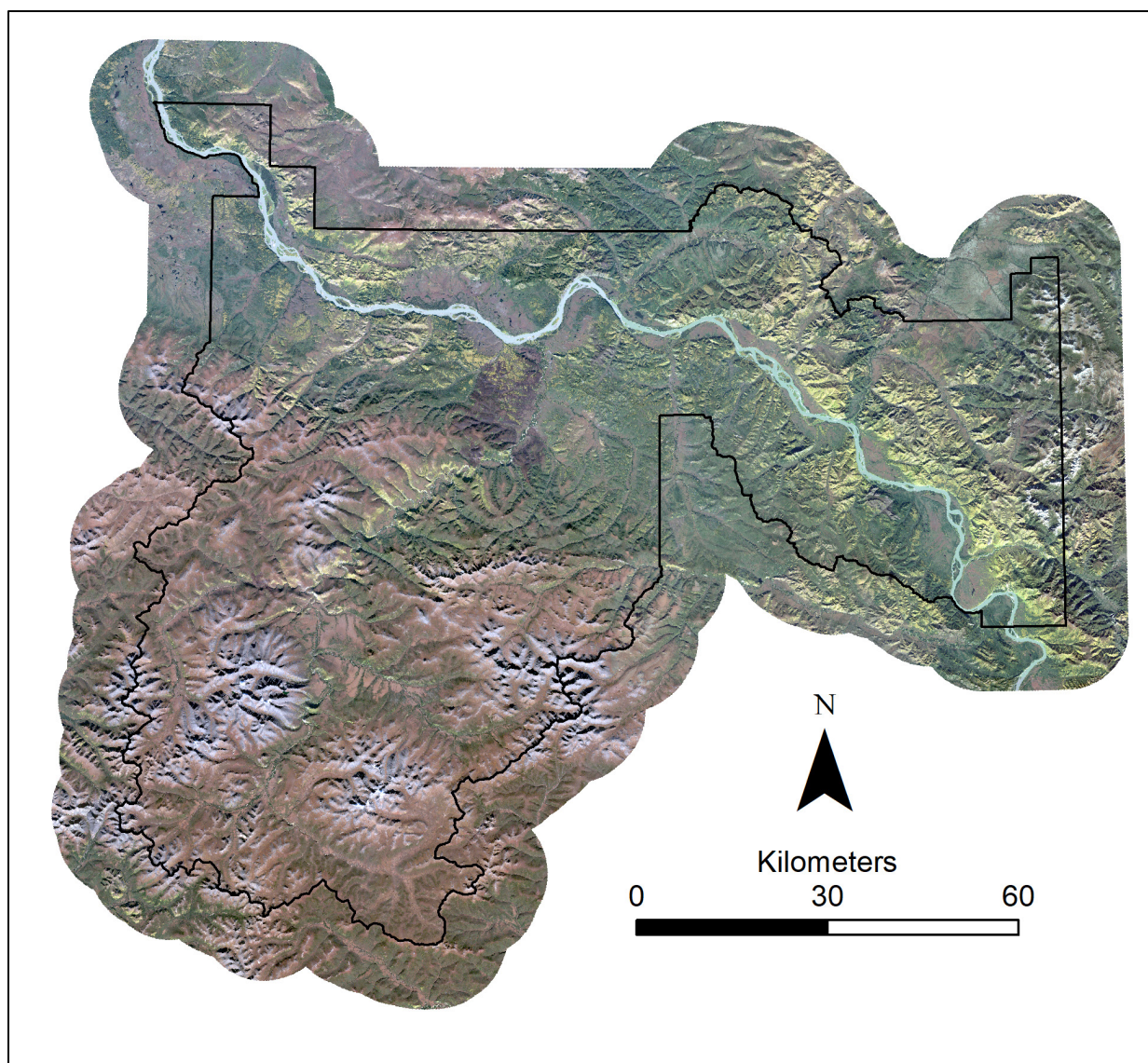


Figure 4. Fall composite Sentinel-2 satellite image, presented in a true color scheme.

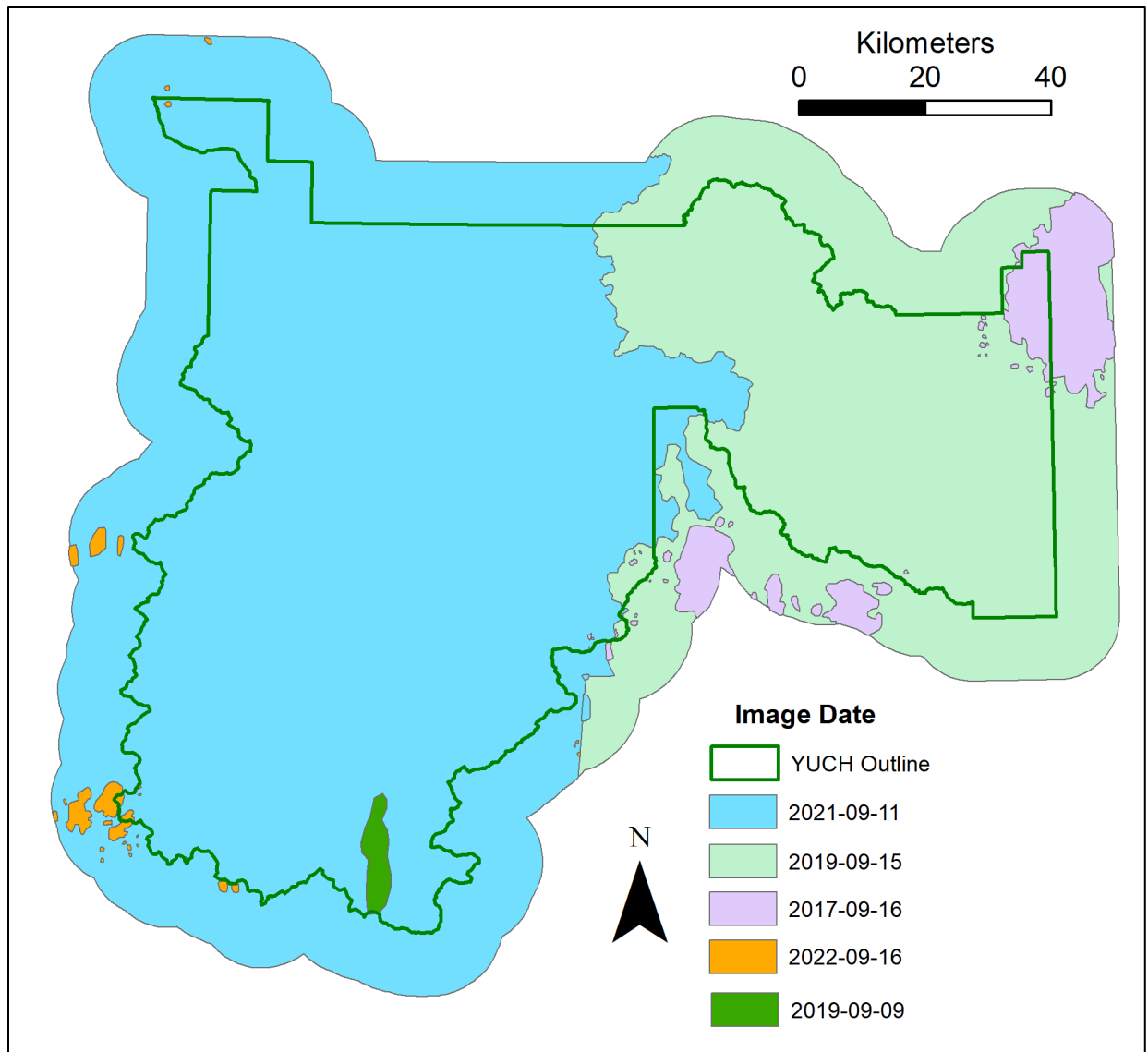


Figure 5. Image dates used in the Sentinel-2 fall composite.

The tiles within a single UTM zone join seamlessly, so I joined tile 06WXS to 06WXT in the original UTM zone 6 coordinate system, and I joined tile 07WDM to 07WDN in original UTM zone 7 coordinate system. Then to produce a Preserve-wide mosaic, I projected the resulting two composite tiles (06WX* and 07WD*) to the Alaska Albers coordinate system (NAD 1983 CORS 96 Alaska Albers, snapped to match topographic data described below) using nearest neighbor resampling, and merged them. Where the data from the two UTM zones overlapped, they differed slightly due to the re-projection process, and I gave priority to the zone 6 composite because it covered a larger portion of the Preserve.

Elevation, Topography, and Vegetation Height

Topographic and vegetation height data were derived from the Alaska statewide IFSAR (radar) digital elevation model (DEM; USGS 2018). All DEM-derived data were aggregated to 10 m resolution to match the Sentinel-2 data, with the pixel boundaries on even 10-m distances in the Alaska Albers coordinate system. I retained the original NAD 1983 CORS 96 Alaska Albers coordinate system of the DEM data and created or projected all other GIS data layers to match it.

Elevation

Simple elevation is a useful substitute for climatic factors including temperature, precipitation, and windiness. It was particularly valuable for distinguishing alpine vegetation types.

Slope

Slope steepness (measured in degrees) is useful because steep slopes are subject to erosion and, all else being equal, steep slopes are drier (because water runs off). Slope is also used to compute “southwestness” and “southeastness”, described below.

Southwestness

Microclimate varies greatly in our area as a result of exposure to solar radiation. To account for total annual solar radiation “heat load” (after McCune and Keon 2002 and Beers 1966), I calculated “southwestness”, an index which reaches its maximum on steep slopes that face southwest (azimuth 225 deg). To make the index reach its maximum at a sun azimuth of 225°, I took the cosine of the slope’s azimuth (A) minus 45°, and multiplied it times the tangent of the slope steepness (S):

$$\text{Southwestness} = -\tan(S) \cos(A-45)$$

This computation was performed on the original 5-m resolution data and then aggregated to 10 m resolution using the mean of the 4 pixels involved.

Southeastness (illumination index)

The brightness and to some extent also the color of satellite images is affected by the direction a slope faces relative to the sun. In fact, steep north-facing slopes are in shadow and appear nearly black in images. I did not attempt to balance the Sentinel-2 reflectance images for illumination effects on slopes. Instead, I included an index of illumination as a classification variable so that, in effect, I could train the classifier for the apparent reflectance of Sentinel-2 images on various slopes and aspects. The satellite is on a sun-synchronous orbit the passes overhead at 10:30 local time. The sun travels at 15° per hour, so at 10:30 AM it is 22.5° east of south, or at 157.5°. Thus, to get the angle from 10:30 solar time, I added 22.5 to the aspect and used a formula similar to the one used above for “southwestness”:

$$\text{Illumination index} = -\tan(S) \cos(A+22.5)$$

The calculations were performed on the original 5 m resolution data and the result was aggregated to 10 m with a mean summary. The illumination index was added as a 5th band to the Sentinel-2 data and used in the classification like a 5th reflectance band, to account for differences in illumination due to slope steepness and aspect.

Curvature

Topographic curvature can be related to vegetation because convex slopes force runoff to diverge and are thus by nature drier than flat or concave slopes. Topographic curvature was computed by processing the elevation each pixel with the negative of a Laplacian-type filter of 25 m radius, which produced higher values on convexities:

```
0  1  1  1  0
1  0  0  0  1
1  0 -12  0  1
1  0  0  0  1
0  1  1  1  0
```

I truncated the result at zero, because strong concavities (negative curvatures) are typically locations with streams where runoff removes the excess water, and thus the strongly negative curvatures there would misleadingly imply very wet conditions. In our area, flat areas can be entirely waterlogged and increasing concavity doesn't proportionally increase wetness. Also, the results of this filter are essentially the sum of slopes away from the point, which exaggerates the effect of larger slopes on runoff; so I took the square root of the value produced by the filter, in keeping with open-channel flow equations (e.g., the Manning and Hazen-Williams equations) which compute flow velocity as the square root of slope.

Vegetation Height

The vegetation height was taken from the IFSAR DEM, where it was computed as the difference between the highest surface and the bare earth, and aggregated to 10 m resolution, this time using a median summary. The IFSAR vegetation height appeared to be generally reliable in the study area, except on some steep slopes. In gently sloping areas known to be barren of vegetation (e.g., alpine areas) the values were generally ± 15 cm, suggesting that this might be the accuracy limits of this layer.

Image Smoothing

I smoothed the Sentinel-2 reflectance data using an edge-preserving smoothing filter, devised for this project, that involves two steps. First I applied a median filter of each wavelength band, for a circle with 35-m radius. This circle gathers data from a 37-pixel neighborhood (i.e., 3700 m² area):

```
0  0  1  1  1  0  0
0  1  1  1  1  1  0
1  1  1  1  1  1  1
1  1  1  1  1  1  1
1  1  1  1  1  1  1
0  1  1  1  1  1  0
0  0  1  1  1  0  0
```

The median is inherently better at preserving edges than a mean filter, but to further increase the edge preservation of the median filter, I compared the original value of the center pixel to the 37-pixel medians of the surrounding 8 neighboring pixels and the center (i.e., its own median), using Euclidean distance of all 4 bands together. The median that most closely resembled the original value of the central pixel was assigned to the center. This new value I call the “shifted median”. It recovers

some of the edge detail lost in the median filter process (Figure 6). To increase consistency between the summer and fall images in the spatial objects visible, I computed the shift using the fall image and applied these shifts to the summer image also. For example, if the best match between the center and its neighboring medians on the fall image was the neighbor to the north, I assigned the median for the neighbor to the north on the summer image also.

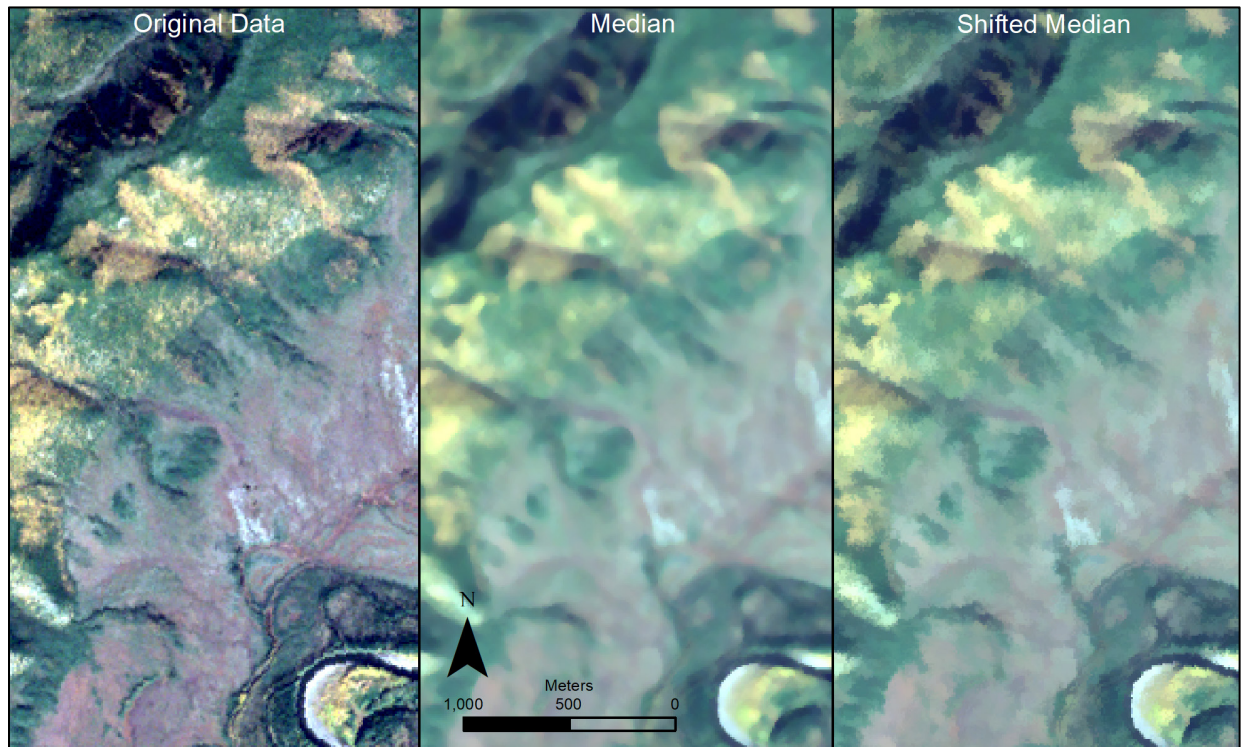


Figure 6. Smoothing of a fall Sentinel-2 satellite image (left) with the median (center) and shifted median (right). The scene is centered near longitude 142.35°, latitude 65.44°, with the Kandik river visible in the lower right.

The goal of the edge-preserving filter was to create a smoothed image source that resembled a segmented image (frequently used in image classification), without creating hard boundaries in arbitrary locations as a segmenter would. This allowed the training data to have more influence on boundary locations in the final map. See the Discussion for more about this choice of methods.

The topographic variables and vegetation are naturally smoother than the spectral data, so I simply smoothed them with the median of a 25-m circle (21 pixels, 210 m²):

```

0  1  1  1  0
1  1  1  1  1
1  1  1  1  1
1  1  1  1  1
0  1  1  1  0

```

Note that due to the smaller radius, the smoothing window for the topographic features was almost completely contained within the window for the spectral features, even when the latter was shifted as described above.

A median filter applied to a window containing two strongly contrasting features (e.g., water and land) with a sharp edge will return a value that represents the feature covering the majority of the window. This means that, in principle, an object covering just over half of the 35-m circular neighborhood is the smallest that could be well represented and available to be classified. In other words, a 10-m pixel image smoothed by the method used here actually represents an area between 3700 m² (the full window in the case of a uniform area) and about 2000 m² (the minimum sized strongly contrasting object that could dominate the median). These are 0.2 to 0.37 ha, or 0.5 to 0.9 acres, respectively.

Legend

The legend was developed interactively with gathering of training data. I attempted to recognize the land cover classes used by the previous mapping effort (DU 2002), with finer detail from the plant associations defined by Boggs and Sturdy (2005) and the USDA-NRCS ecological sites and phases recognized in the study area by Parry (2013). The final legend and land cover type descriptions are given in the Results.

Classification

Training data

Training data was defined by points digitized manually to represent examples of the land cover types, as interpreted from the imagery. These points were used to extract spectral and topographic data from their underlying pixels, which as described above represent the median of an area of 21 (DEM) or 37 (spectral reflectance) pixels. Training points were deliberately chosen away from obvious type boundaries, to ensure that the median data represented by the pixel intersected by the point was computed from 37 pixels (spectral data) or 21 pixels (topographic data) of the type matching the label in the point. The locations of the training points were chosen by reference to the Sentinel-2 image data (summer and fall, described previously), the 1-m resolution color-infrared, digitized aerial photograph mosaic of YUCH from 2007 owned by NPS, and, less frequently, the 0.5 m resolution Worldview image mosaic (2013–2020) provided by the Web Mapping Service

“ahri_2020_cir_cache” at

https://geoportal.alaska.gov/arcgis/services/ahri_2020_cir_cache/MapServer/WMSServer?

I also used digital raster graphics of the US Geological Survey topographic maps of the Preserve and the spectral data sources listed above to infer elevation, slope steepness, and slope aspect while locating training points. To improve my ability to recognize the vegetation represented by features visible on the images, I consulted plot data from the sources in Table 2. A total of 2802 training points were digitized. They were widely distributed across the Preserve, and the less widespread types had fewer training points but a higher density of points per unit area of each type. Detailed information about the number of training points by type is presented in the Results.

Table 2. Vegetation plot data sources.

Project	Count of Plots	Years	Reference
USDA-NRCS Soil survey of YUCH	910	2008–2010	Parry 2013
Central Alaska Inventory and Monitoring Network vegetation plot database	690	2006–2016	Roland et al. 2004
YUCH the Breeding Landbird Inventory of Yukon-Charley Rivers National Preserve, Alaska	726	1999–2000	S. A. Swanson and Nigro 2003
Plant Associations and Post-fire Vegetation Succession YUCH	76	2003	Boggs and Sturdy 2005
Yukon-Charley/Black River/Fortymile Earth Cover Classification	364	1997	Ducks Unlimited 2002

Classifier

I used a modification of the k-nearest neighbor (knn) classifier. A standard knn classifier computes the distance between each unknown object (in my case, each pixel on the smoothed image) and the training data, and assigns the class of the nearest neighbor (or the majority of k nearest neighbors) in the training data to the unknown pixel. Note that the distance here is not distance in space, but distance as computed from the difference between training data and the unknown's data for spectral and topographic data. So in effect “distance” is the inverse of “similarity” of each pixel to its closest match in the training data. I used Euclidean distance (distance computed by the Pythagorean theorem).

The distances were scaled using the standard deviation of the values in each training set (for the Sentinel-2 reflectances) or the whole study area (for the topographic variables). The reason for scaling with the whole study area for the topographic variables is that there is very little variation of some topographic properties within many of the vegetation classes: many occur on flat sites with little slope, curvature, or “southwestness”. A standard deviation computed within such a group would be very small, and using it to scale the values would greatly exaggerate the importance of slight, relatively insignificant variations. Use of the study-area wide standard deviations avoids this problem.

My modification of the knn method was to compute the distance from each pixel to the 2nd nearest neighbor in each cover class individually. This produces a map of the distance from each pixel to the second closest match it had in each class in the training data. In a second step, for each pixel I scanned through these distance maps for all of the classes, and chose the class with the smallest distance as the “winning” class.

The 2nd nearest neighbor method had two distinct advantages: 1) it provided some smoothing of the training data, removing the influence of any single anomalous training point. The distance to the 2nd nearest neighbor is equivalent to the median distance to the 3 nearest neighbors. 2) It allowed the training points to be verified by the leave-one-out method. Any pixel containing a training point will have that training point as its nearest neighbor (because the distance to itself is zero), but by the 2nd nearest neighbor method it will be classified using all of the other training points, not itself, and the

match between the “known” class and the “computed” class can be compared. Leave-one-out cross validation is especially well suited to data sets like mine, where some of the classes have small samples (Wong 2015).

Computation of distance for one class at a time also provided several advantages. First, it allowed me to reprocess only part of the data if revisions were made to the training data for just one or a few classes (as is typical when refining the classes and training data). Second, it allowed me to easily restrict certain classes to certain parts of the study area, as defined by separate polygon layers (riparian zones, calcareous rock areas, etc., described below). It allowed me to scale the spectral distances individually within each class using the standard deviation of the class. Finally, it allowed me to use the second nearest-neighbor verification method as described above, which is not an option in standard knn classification.

To compute the distances to the 2nd nearest neighbor, I modified the “kknn” function of the R package kknn (Schliep and Hechenbichler 2016). This package has very efficient modules for computing distances, but the full kknn function has many other time-consuming features that make it difficult to apply to a very large test data set, in my case a 257 megapixel raster (163 Mpx with data) with 14 data layers. My modification was simply to comment out all of the code in the original kknn function after the computation of the distances (line 83):

```
D <- matrix(dmtmp$dm, nrow = p, ncol = k + 1)
```

And modify the final output statements (the last 3 lines of the function) to save only the distances:

```
result <- list(D = D)  
class(result) = "kknnD"  
result
```

The function automatically saves k+1 distances (where k is the number of nearest neighbors desired), so one need only choose k = 1 when running the function to get the 2nd nearest neighbor. A test on my data showed the modified function to run about 30 times faster than the original full function. To compute distances for the whole study area to a single class took about 40 minutes.

The single-class distance method also opened up options for how to deal with numerous classification variables of different types. In a normal knn analysis, the distance is computed using all variables simultaneously, and the final result is based on a single nearest neighbor (or set of k nearest neighbors). With the single-class method I computed separately the distance to the 2nd nearest neighbor on the summer Sentinel-2 image, the fall Sentinel-2 image, the topographic features, and the vegetation height, and then combined them. Because the data were scaled using the standard deviation, the distance units are also in unitless standard deviations, but each Euclidean distance becomes larger as more dimensions are added. I converted the four Euclidean distances into root mean square distances by dividing them by the square root of the number of dimensions used in each. Then I took the mean of these four values:

```
d = (s/(5^0.5) + f/(5^0.5) + t/(4^0.5) + v)/4
```

where d is the overall distance and s , f , t , and v are the summer, fall, topographic and vegetation height distances. The result is a measure of distance that is scaled in units of standard deviation, with each of the four types of data (summer reflectance, fall reflectance, topographic data, and vegetation height) weighted the same. If any of these values is large for a given pixel and vegetation class, d will be large and the class will be unlikely to be chosen (because some other class will have a smaller d). Note that the same training data point will typically not be chosen as the nearest neighbor for all of the 4 data types, as it would have been if I had combined all 14 classification variables into one Euclidean distance measure. I chose not to compute one distance using all of the variables because it is much less demanding of the training data. If they were combined, one would have to find points representative of the full range of colors at all different elevations, for example. Since reflectance should be similar regardless of the elevation where the type occurs, it is appropriate to evaluate them separately. Variables that are strongly correlated were combined in the distance analysis, e.g., all the summer wavelength bands. Note that my measure of illumination was combined with the four reflectance measures into a single reflectance distance measure, because they are strongly correlated.

After computing the distance for each pixel to a class, I smoothed them with a circular 25-m radius median filter as described above under “Smoothing”.

Masking

Some vegetation types occur in specific regions of the study area only, and these types are otherwise difficult to distinguish by the classification variables used. For example, deciduous forests in active riparian areas are usually poplar (*Populus balsamifera*), while outside of riparian areas they are usually birch (*Betula neoalaskana*) or aspen (*Populus tremuloides*). However, these two types have similar reflectances on images, and both can occur on flat surfaces, and therefore they are difficult to distinguish by reflectance and topography alone. Thus, I digitized riparian areas and restricted these types to be either only inside or outside of the riparian areas as appropriate. This was readily accomplished by simply deleting the distance values for each type (e.g., Riparian Poplar Forest) in the areas where it is known to be rare or absent (e.g., non-riparian areas). The masks and types they were applied to are listed in Appendix B. The fire perimeter masks were taken from AICC (2022) for years up to 2021. I digitized fire perimeters for 2022 from the summer composite Sentinel-2 image created here.

Class Selection and Final Modal Smoothing

After masking I had a set of rasters for each cover class that contained the distance of each pixel to that class (as determined by the distance to the second nearest neighbor in the training data). This distance was the inverse of the similarity, and the type with the smallest distance would be the cover type that was most similar to the pixel. So I created a stack containing the distance to each type, and for each pixel chose the type with the smallest distance. I also saved the value of the minimum distance, which was useful for identifying areas that had no good matches in the training data. Several tentative types were not reliably separable and were merged after classification of the image.

As a result of the image smoothing described previously, the types usually occur in large patches. There are, however, isolated individual pixels or small groups of pixels that belong to a single class. To remove these while preserving edges of larger patches, I ran a shifting window smoothing

operation similar to the one used previously to smooth the original image data. I used a 25-m radius circular window (21 pixels) and found the modal class (the most frequent class). If the original class for the center pixel matched the 21-px modal value for any of its 8 neighbors or its own modal value, then that original class was retained. If not, then the new modal class was accepted. This had the effect of eliminating most patches that were less than 10 px (1000 m²) in size, or linear strips that were just 1 or 2 px wide.

Training Verification

I used Principal Components Analysis (PCA) to look for misclassified training points and to verify that the proposed vegetation types were indeed separable. PCA was very useful, because the distances displayed in a PCA plot are very similar to the Euclidean distances used in the classification. I ran PCA on pairs of types that could be confused, and displayed them on a scatterplot with principal component axes 1 and 2 (which contain most of the variation) for the summer, fall, and topographic data. An example is given in Figure 7. In this example, the PCA plots suggest that Alpine Dwarf Shrub and Alpine Low Shrub overlap somewhat in topographic properties and fall reflectance, but are separable on the summer image; this was confirmed by observations of the denser, greener vegetation of Alpine Low Shrub on the summer images.

When I observed obvious outliers on these plots I located the points on the images and, if any did indeed turn out to be misidentified, I either moved or re-labeled them. In some cases overlap could not be rectified, because the types indeed overlap in the available spectral and topographic properties. In these cases if the area of overlap was minor and the types important (e.g., Wetland Low Shrub and Black Spruce Woodland, see the Results), I retained the types and accepted the fact some error on the maps would result. In a few cases I merged tentative minor types after noting serious overlap.

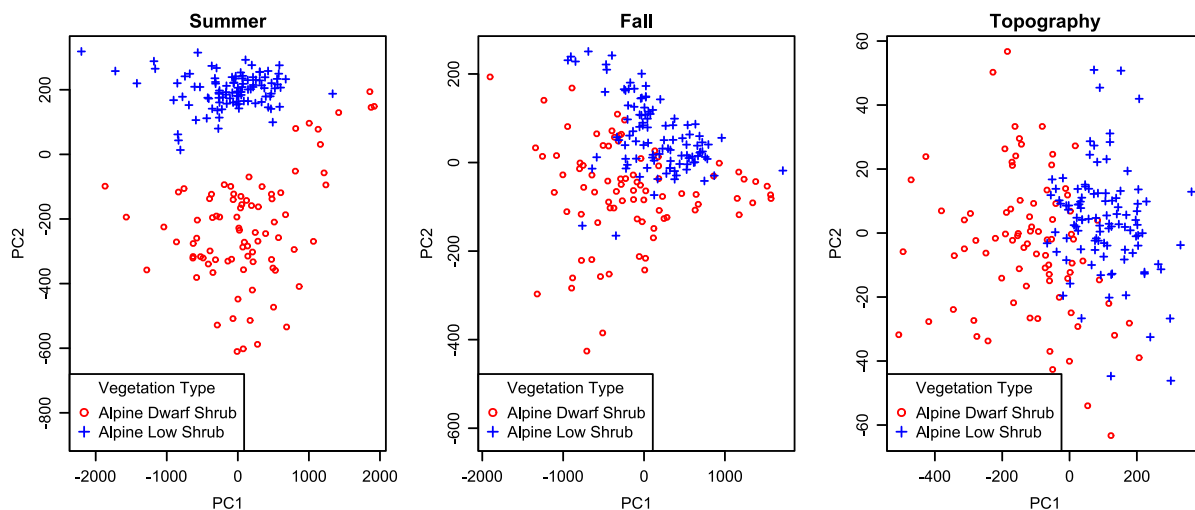


Figure 7. Example Principal Components Analysis plot. “Summer” and “Fall” refer to the Sentinel-2 reflectance data from those seasons. “Topography” is the ensemble of DEM-derived data (elevation, slope steepness, “southwestness”, and curvature. The axes “PC1” and “PC2” refer to principal components 1 and 2, which summarize most of the variability in the original 4 data variables. Points are individual training points. Summer reflectance provides good separation between these two types.

Random Forest Classification

For comparative purposes I also ran a Random Forest (RF) classifier on the same data, using the R package “randomForest” (Liaw and Wiener 2002), which implements the original algorithm by Brieman (2001), using all of the default settings. To include the “mask” information discussed above, I created binary rasters of each mask (a value of 1 inside the mask, 0 outside) and used these as additional classification variables.

Results

The final mapping legend contains 38 land cover classes, including 31 vegetation types, water, and six different types of sparsely vegetated or barren areas. Brief descriptions of the types are given in Table 3, with the definitions of the vegetation structural terms used given in Table 4. A key to the land cover types is provided in Appendix B.

Table 3. Land cover type descriptions. For definitions of vegetation structural terms (“open”, “closed”, “tall” “mixed”, etc.), see Table 4.

Cover Type Number	Cover Type Name	Description
1	Water	Rivers, lakes, and ponds
2	AquaticVegetation	Herbaceous, submersed, floating-leaved, and sparse emergent aquatic vegetation
3	RiparianBarrens	Unvegetated or very sparsely vegetated (less than 10% canopy cover) areas along rivers.
4	MineTailingBarrens	Sparsely vegetated mine tailings of coarse-grained rock fragments, along Coal and Woodchopper Creeks.
5	RiparianLowShrub&Herb	Riparian areas with herbs, low shrubs (mainly willows <i>Salix</i> and alders <i>Alnus</i>), and small trees (mainly poplar <i>Populus balsamifera</i>) less than 1.5 m tall. Shrub cover ranges from absent to closed (>75%).
6	RiparianTallShrub	Riparian deciduous tall shrubs (mainly willows and alders), and small trees (mainly poplar), mostly closed (over 75% cover) and 1.5 to 3 m tall.
7	RiparianYoungPoplarForest	Riparian balsam poplar open forest, 3 to 7 m tall, with deciduous tall shrubs (mainly willows and alders).
8	RiparianPoplarForest	Riparian balsam poplar forest, more than 7 m tall, closed, or open with significant tall shrub cover of alders or willows.
9	RiparianMixedForest	Riparian mixed white spruce (<i>Picea glauca</i>) and broadleaf deciduous forest, open or closed, more than 7 m tall. Deciduous trees are mostly balsam poplar, but may be paper birch (<i>Betula neoalaskana</i>), especially in less frequently flooded areas and along smaller rivers.
10	RiparianWhiteSpruce&Alder	Riparian open white spruce forest (25% to 60% cover), more than 7 m tall, with alder understory >25% cover and clearly visible in gaps between trees.
11	RiparianWhiteSpruceForest	Riparian white spruce forest, more than 7 m tall, with alder understory <25% cover, or the understory is obscured by trees and tree shadows, with tree cover >40%.
21	WetHerb&Moss	A variety of wetland vegetation types in depressions and along small lakes and ponds. Includes communities dominated by sedges (<i>Carex</i>), mosses, and low shrubs.

Table 3 (continued). Land cover type descriptions. For definitions of vegetation structural terms (“open”, “closed”, “tall” “mixed”, etc.), see Table 4.

Cover Type Number	Cover Type Name	Description
22	WetlandLowShrub	Wet lowland low shrubs, consisting of mostly ericaceous shrubs (Labrador tea <i>Ledum palustre</i> , blueberry <i>Vaccinium uliginosum</i>) and shrub birch (<i>Betula nana</i>), with ground cover dominated by mosses and cottonsedge (<i>Eriophorum vaginatum</i>).
23	BlackSpruceWoodland	Lowland black spruce (<i>Picea mariana</i>) woodland, (10 to 25% tree cover), with a low shrub understory like type 22.
24	LichenLowShrub&Woodland	Wetland low shrubs (see type 22) and black spruce (<i>Picea mariana</i>) woodland (0–25% cover) with ground cover dominated by lichens, or lichen and moss co-dominant.
25	BlackSpruceForest	Mostly open forest (25 to 60% tree cover), occasionally closed (more than 60% cover). Dominantly black spruce, with some white spruce, especially where the latter is short-statured (< 7 m tall), on gentle slopes with wet, organic soils at low elevations.
31	TallShrubSeral	Deciduous tall shrubs and trees, open or closed (more than 25% cover), 1.5 to 3 m tall. Includes alder and willow shrubs, and small paper birch and aspen (<i>Populus tremuloides</i>) trees. Mostly below 800 m elevation, non-riparian, and seral post-fire.
32	DeciduousForestShort	Broadleaf deciduous forest of short trees, 3 to 7 m tall, open (25–60% cover) or closed (more than 60% cover) with alder tall shrubs. Mainly paper birch <i>Betula neoalaskana</i> , also aspen trees. Occurs predominantly on old (c. 1970) burned areas.
33	DeciduousOpenForest&Woodland	Open broadleaf deciduous forest or woodland (less than 50% cover) on dry, south-facing slopes, usually steeper than 20°. Mainly aspen with lesser amounts of paper birch, balsam poplar, and white spruce. Common understory shrubs are the species listed for type 42, and bearberry (<i>Arctostaphylos uva-ursi</i>).
34	DeciduousForest	Broadleaf deciduous forest, mostly closed canopy (more than 60% cover) and more than 7 m tall. Mainly paper birch with some aspen. Common understory shrubs are rose (<i>Rosa acicularis</i>), willow, and alder.
35	MixedForestShort	Mixed broadleaf deciduous and spruce forest of short trees, 3 m to 7 m tall. White and/or black spruce, and paper birch, with lesser amounts of aspen. Forest is mostly open (25–60% tree cover) with significant tall shrub cover, mainly alder and willow.
36	MixedOpenForest&Woodland	Open mixed broadleaf deciduous and spruce forest, (tree cover less than 50%), on dry, south-facing slopes, usually steeper than 20°. Mainly white spruce, and aspen, with lesser amounts of paper birch. Common understory shrubs are the species listed for type 42, and bearberry (<i>Arctostaphylos uva-ursi</i>).

Table 3 (continued). Land cover type descriptions. For definitions of vegetation structural terms (“open”, “closed”, “tall” “mixed”, etc.), see Table 4.

Cover Type Number	Cover Type Name	Description
37	MixedForest	Closed (>60% tree cover) and open (25–60% cover) mixed broadleaf deciduous and spruce forest, More than 7 m tall. Mainly white spruce and paper birch, also black spruce and aspen. Common understory shrubs are rose, willow, and alder.
38	UplandSpruceForest	Open spruce forest, mainly white spruce but also some black spruce, on mesic to dry sites.
40	BluffBarrens	Unvegetated steep slopes at low elevations near rivers.
41	DryHerbaceous	Grass-dominated herbaceous vegetation with scattered low shrubs (less than 25% cover), on dry, south-facing slopes.
42	DryLowShrub	Low shrubs on dry, south-facing slopes. Most commonly rose (<i>Rosa acicularis</i>), and small aspen trees, also serviceberry (<i>Amelanchier alnifolia</i>), soapberry (<i>Shepherdia canadensis</i>), silverberry (<i>Elaeagnus commutata</i>), and juniper (<i>Juniperus communis</i>).
50	Burned2021-2022	Areas burned in 2021 or 2022 and dominated by a blackened surface with little vegetation canopy cover in 2022. By 2023 or 2024 will have vegetation be like unit 51.
51	LowShrub&HerbBurned2015-2020	Areas burned in 2015–2020 with incomplete cover by mosses (especially <i>Ceratodon purpureus</i>), liverworts (<i>Marchantia</i>), herbs (especially <i>Calamagrostis canadensis</i> , <i>Epilobium angustifolium</i> , and <i>Eriophorum vaginatum</i>), resprouting shrubs, and trees less than 1.5 m tall.
52	UplandLowWillow	Upland areas with mesic to dry low scrub dominated by willow. Occurs mainly areas burned by wildfires in the years 1999–2013.
53	UplandLowShrub	Upland areas with mesic to dry, open or closed low scrub dominated by ericaceous shrubs (<i>Ledum</i> , <i>Vaccinium</i>) and shrub birch. Occurs mainly areas burned by wildfires in the years 1999–2013.
54	SpruceWoodland&ShrubNorth	Steep north-facing slopes with black spruce woodland; also terrain shadow with undifferentiated vegetation of spruce woodland and forest, low- or tall shrubs, and barrens.
60	AcidicBarrens	Areas at high elevations on non-calcareous rocks, with little vegetative cover except lichens, mainly south of the Yukon River.
61	AlkalineBarrens	Areas at high elevations on calcareous rocks, with little vegetative cover except lichens, mainly in the Ogilvie Mountains north of the Yukon River.
62	AlpineDwarfShrub	Alpine dwarf shrubs (less than 20 cm tall). Common shrubs are dryas (<i>Dryas</i> sp.), blueberry (<i>Vaccinium uliginosum</i>), lowbush cranberry (<i>Vaccinium vitis-ideae</i>), crowberry (<i>Empetrum hermaphroditum</i>), and others. Also sedges (<i>Carex</i>) and a variety of forbs.

Table 3 (continued). Land cover type descriptions. For definitions of vegetation structural terms (“open”, “closed”, “tall” “mixed”, etc.), see Table 4.

Cover Type Number	Cover Type Name	Description
63	AlpineSedge&DwarfShrub	Alpine mesic to dry sedge (<i>Carex bigelowii</i>) and other graminoids and dwarf shrubs: birch (<i>Betula nana</i>), blueberry, Labrador tea, lowbush cranberry, crowberry, and others. Graminoid cover equals or exceeds dwarf shrub cover.
64	AlpineLowShrub	Alpine and subalpine low shrubs: willow, shrub birch, blueberry, Labrador tea, and others.
65	SubalpineTallShrub	Tall shrubs (willows, alder) open or closed (more than 25% cover), above 700 m elevation. Mostly not located in areas of historical (post-1950) wildfires.
66	TussockTundra	Cottonsedge (<i>Eriophorum vaginatum</i>) tussocks with low shrubs ericaceous shrubs and birch), above 600 m elevation.
67	LichenTundra	Lichen-dominated mesic tundra with low shrubs and sedges (<i>Carex</i>).
68	SubalpineSpruceWoodland	Subalpine spruce woodland (10 to 25% tree cover) near tree-line (elevation 800–1200 m). Mainly white spruce with some black spruce. Ground cover dominated by feathermosses (<i>Hylocomium splendens</i> and <i>Pleurozium schreberi</i>)
69	SubalpineSpruceLichenWoodland	Spruce woodland (10 to 25% tree cover) with lichen-dominated ground cover. Mainly white spruce with some black spruce. Occurs at mid- to high elevations (600 to 1100 m).

Table 4. Definitions of the vegetation structural terms used in the cover type descriptions. Definitions follow Viereck et al. (1992) except for the short/tall tree distinction, which follows Boggs and Sturdy (2005).

Category	Term	Definition
Shrub height	Dwarf	less than 20 cm tall, even when mature
Shrub height	Low	20 cm to 1.5 m tall.
Shrub height	Tall	1.5 m to 3 m tall
Tree height	Short	3 m to 7 m tall
Tree height	Tall	More than 7 m tall
Tree cover	Woodland	10% to 25% tree canopy cover
Tree cover	Open Forest	25% to 60% tree canopy cover
Tree cover	Closed Forest	More than 60% tree canopy cover
Forest composition	Broadleaf deciduous	More than 75% of the tree canopy cover is broadleaf deciduous trees
Forest composition	Mixed	Both broadleaf deciduous and spruce trees occupy 25% to 75% of the tree canopy
Forest composition	Spruce	More than 75% of the tree canopy cover is spruce

For more comprehensive descriptions of the vegetation types, with species lists and soil descriptions, see the descriptions in Boggs and Sturdy (2005) and Parry (2013). The land cover types mapped here are linked to the corresponding types described by these two studies in Appendix C, Tables C1 and C2, with page numbers listed to facilitate looking up the descriptions. For convenience these two publications are linked with other materials from this project in the NPS Data Store at <https://irma.nps.gov/DataStore/Reference/Profile/2297197>.

In addition, see Appendix C for the classification of the Land Cover Types by the US National Vegetation Classification System (USNVC 2023, Table C3) and the Alaska vegetation classification system of Viereck et al. (1992, Table C4). A crosswalk between the Land Cover Types mapped here and those in the previous YUCH land cover map (Ducks Unlimited 2002) is in Appendix Table C5.

Finally, Appendix Table C6 presents several simplified legends for the map. Two are based on the hierarchy of the Alaska vegetation classification (Viereck et al. 1992): a simplified legend based on level II classes with 11 land cover classes; and a more simplified legend based on level I with 6 classes. For the most part these classes follow directly from the Viereck et al. (1992) level III equivalents in Table C4, with the addition of a few classes for non-vegetated cover types. In a few cases my land cover types span the Viereck et al. (1992) level II and I types (e.g., map type 23 contains both woodland and dwarf tree scrub), so I subjectively chose the dominant type for Table C6. A third simplified legend aggregates the 38 land cover classes into 13 “Ecological” classes, which are groups of cover classes that I judged to be ecologically similar. For example, the various lowland black spruce and wet shrub types are joined together into “Lowland Spruce Forest & Shrub”; these types share many plant species in common, along with wet, organic soils over permafrost. Appendix Table C6 is also provided in text format at the project’s IRMA site (see above). It can be downloaded and linked to the map raster attribute table in a GIS to portray the simplified types in map form.

The areas covered by each type vary widely, from less than 1 km² for mine tailing barrens to about 2100 km² for subalpine spruce woodland (Table 5). The number of training points used per type varied from 16 for Lichen Tundra to 175 for Wetland Low Shrub (Table 5). The total count of points was lowest for types that cover a small area and occur in a limited area, such that few examples were available. However, the area of the cover type represented by each point was very consistently smaller for the smaller types (Figure 8), i.e., the density of training points was greater in the small types. In other words, to adequately represent rare types required more intensive sampling in the limited areas where they occurred.

Table 5. Cover type areas, training point counts, and area per point of the types.

Map Value	Class Name	Area (in Preserve, km ²)	Area (in Preserve, %)	Area (whole map, km ²) ^A	Count of Training Points	Area per Point (km ²) ^A
1	Water	165.1	1.6	194.3	129	1.51
2	AquaticVegetation	1.5	<0.05	2.6	19	0.14
3	RiparianBarrens	43.2	0.4	48.7	93	0.52
4	MineTailingBarrens	0.8	<0.05	0.8	35	0.02
5	RiparianLowShrub&Herb	67.8	0.7	95.9	70	1.37
6	RiparianTallShrub	9.8	0.1	11.8	52	0.23
7	RiparianYoungPoplarForest	24.5	0.2	29.1	68	0.43
8	RiparianPoplarForest	16.1	0.2	16.7	39	0.43
9	RiparianMixedForest	44.4	0.4	57.2	62	0.92
10	RiparianWhiteSpruce&Alder	17.7	0.2	25.1	25	1.00
11	RiparianWhiteSpruceForest	12.8	0.1	16.8	86	0.20
21	WetHerb&Moss	3.8	<0.05	6.9	51	0.14
22	WetlandLowShrub	534.5	5.2	902.6	175	5.16
23	BlackSpruceWoodland	933.3	9.1	1796.8	125	14.37
24	LichenLowShrub&Woodland	26.9	0.3	100.9	98	1.03
25	BlackSpruceForest	897.6	8.8	1525.1	108	14.12
31	TallShrubSeral	555.1	5.4	760.4	71	10.71
32	DeciduousForestShort	428.9	4.2	536.6	112	4.79
33	DeciduousOpenForest&Woodland	163.5	1.6	223.8	37	6.05
34	DeciduousForest	29.5	0.3	35.9	52	0.69
35	MixedForestShort	667.5	6.5	939.5	86	10.92
36	MixedOpenForest&Woodland	66.4	0.7	91.9	30	3.06
37	MixedForest	140.9	1.4	205.4	51	4.03
38	UplandSpruceForest	381.2	3.7	718.7	78	9.21
40	BluffBarrens	22.9	0.2	29.0	38	0.76
41	DryHerbaceous	4.6	<0.05	5.4	25	0.22
42	DryLowShrub	32.0	0.3	41.1	25	1.64
50	Burned2021-2022	156.5	1.5	170.9	67	2.55
51	LowShrub&HerbBurned2015-2020	77.0	0.8	79.2	71	1.12
52	UplandLowWillow	96.4	0.9	186.3	27	6.90
53	UplandLowShrub	171.7	1.7	449.9	64	7.03
54	SpruceWoodland&ShrubNorth	388.6	3.8	546.6	67	8.16
60	AcidicBarrens	579.6	5.7	824.4	109	7.56
61	AlkalineBarrens	37.7	0.4	63.9	36	1.78
62	AlpineDwarfShrub	1072.2	10.5	1693.6	85	19.92

^A Tabulated for the full study area, including the 10 km buffer zone outside the Preserve

Table 5 (continued). Cover type areas, training point counts, and area per point of the types.

Map Value	Class Name	Area (in Preserve, km ²)	Area (in Preserve, %)	Area (whole map, km ²) ^A	Count of Training Points	Area per Point (km ²) ^A
63	AlpineSedge&DwarfShrub	106.8	1	142.6	28	5.09
64	AlpineLowShrub	888.3	8.7	1322.9	167	7.92
65	SubalpineTallShrub	29.4	0.3	51.0	21	2.43
66	TussockTundra	26.2	0.3	28.3	51	0.55
67	LichenTundra	0.7	<0.05	2.5	16	0.16
68	SubalpineSpruceWoodland	1167.6	11.4	2099.8	81	25.92
69	SubalpineSpruceLichenWoodland	122.6	1.2	216.7	72	3.01

^A Tabulated for the full study area, including the 10 km buffer zone outside the Preserve

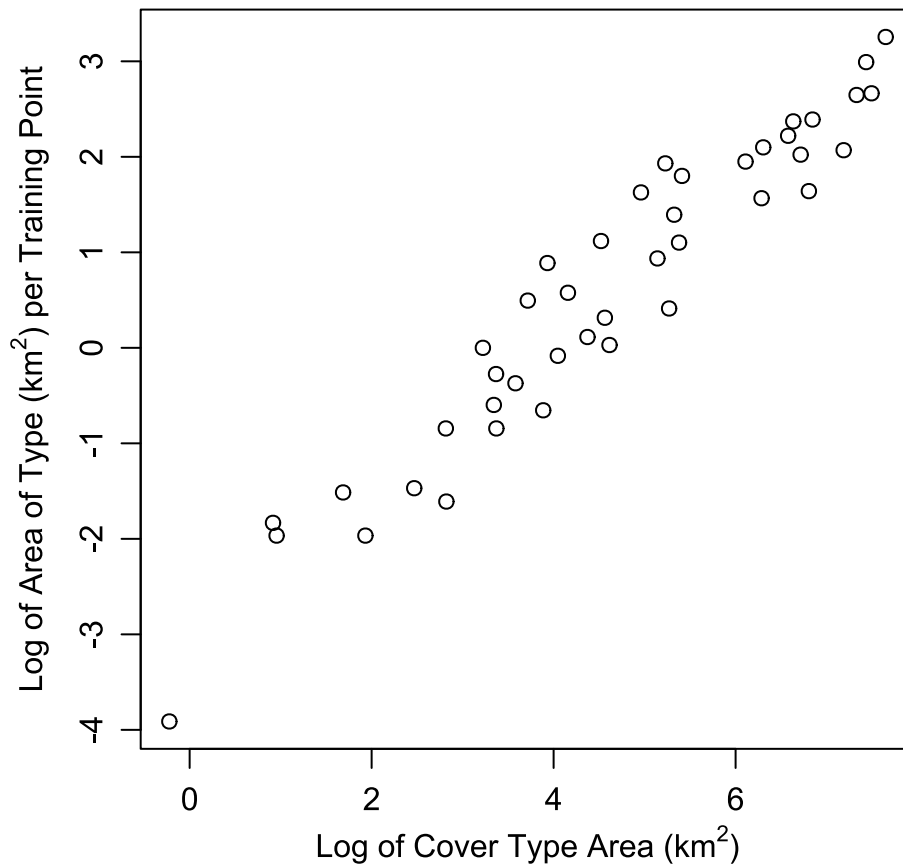


Figure 8. Plot of the area per training point vs. the total area occupied by each cover type.

Comparison with the Previous Map

The largest differences between of the current map and the previous map (Ducks Unlimited 2002; based on a 1991 image) were an apparent decrease in needleleaf forest and increase in dwarf shrub (Table 6). A loss of needleleaf forest is expected, given the area of fires (21% of the Preserve) that occurred between the two map dates. The increase in dwarf shrub was not expected, given the relative stability of alpine areas that is apparent on images. Inspection of these areas revealed that the DU 2002 map had more extensive low shrub in alpine areas than my map, and this difference was due to different mapping thresholds used in the two mapping efforts and not actual change in plant communities. Thus if we assume for comparison's sake that my map is correct (11.5% dwarf shrub in YUCH) and that dwarf shrub area has changed little, the actual area of dwarf shrub in 1991 was probably near this value, and thus higher by 6 to 7% of the area than it was on DU's map, and the area of low shrub in 1991 was correspondingly lower by 6 or 7%, i.e., about 5% of YUCH. Then an increase in low shrub from this revised value of 5% to 12.7% (low shrub area on my map), and the increase in tall shrub from 1.2 (DU) to 5.7% (my map), more than account for the loss of needleleaf forest from 45.5% (DU) to 38.7% (my map).

Table 6. Area occupied by land cover types from the current and previous land cover maps.

Common Class ^A	DU 2002 (%) ^B	Current Study (%) ^C
aquatic-wetland	0	0.1
barren	6.3	7.1
burn	2.1	1.5
deciduous_forest	6.3	6.5
dwarf_shrub	4.9	11.5
low_shrub	11.4	12.7
mixed_forest	9.3	9.0
needleleaf	45.5	38.7
snow	0.3	0
tall_shrub	1.2	5.8
Unmapped (clouds, cloud shadows, terrain shadow)	4.3	0
water	1.8	1.6
wet_low_shrub	6.6	5.5

^A Aggregated classes from both maps that are approximately equivalent

^B Area from Ducks Unlimited 2002 (based on a 1991 Landsat image), within the YUCH boundary

^C Area from this study, within the YUCH boundary

The small area of snow mapped from the August 20, 1991 image is located at the tops of the highest peaks. It represents an early autumn new snowfall and not snowbanks that survived the summer. Thus the lack of snow on my map does not indicate warming-related loss of permanent snow. The most persistent snow/ice visible on my Sentinel-2 images is actually river aufeis on Crescent Creek,

notably near latitude 64.907, longitude –143.984, which was visible on my summer image but not fall image, and thus no snow/ice cover type was recognized in this study.

A similar analysis comparing the current map to the previous one, but restricted to riparian areas only (as defined by my riparian mask), shows a decline in all forest types and a large increase in low and tall shrubs (Table 7). Inspection of the map showed that the DU map classified most deciduous riparian vegetation, including forest, tall shrub, and low shrub, as “deciduous forest”. So most of the shrub increase is due to different mapping methods and not actual change. Some of the decrease in area of needleleaf forest (from 36% to 25% of the riparian zone) could be real change caused by flood erosion and destruction of forests by floating ice in floods. The area of water plus barrens (taken as a sum, because the area of barrens vs. water changes greatly with fluctuations in water level) was nearly constant in both mapping efforts at 38%. These two types are easily mapped regardless of the method used, and their agreement between the two maps confirms this, and it also indicates little change in the area occupied by all vegetation on floodplains in YUCH over the past 30 years.

Table 7. Area occupied by land cover types in riparian zones from the current and previous land cover maps.

Common Class ^A	DU 2002 (%) ^B	Current Study (%) ^C
aquatic-wetland	0	0.2
barren	6.8	9.1
burn	0.4	0.2
deciduous_forest	10.1	7.8
dwarf_shrub	0.2	0.3
low_shrub	0.7	16.4
mixed_forest	11.4	9.8
needleleaf	36.0	24.9
snow	0	0
tall_shrub	0	2.1
unmapped	1.3	0
water	31.5	29.0
wet_low_shrub	1.6	0.2

^A Aggregated classes from both maps that are approximately equivalent

^B Area from Ducks Unlimited 2002 (based on a 1991 Landsat image), within the YUCH boundary

^C Area from this study, within the YUCH boundary

Cover Types, Major Landforms, and Fire

The vegetation of YUCH is clearly strongly affected by fires, and fires have historically been largely confined to specific regions. It is useful to visualize the Preserve in three such regions (Figure 9, Table 8): 1) Riparian areas. Fires are almost nonexistent in the active floodplain of the Yukon River, as a result of natural firebreaks and less flammable vegetation. Vegetation consists of mostly unburned, riparian vegetation types. Vegetation change in riparian areas is generally gradual, by vegetation succession and riverbank erosion. Occasional dramatic flood events causing destruction of vegetation are conspicuous to the river traveler, but cover relatively little relative area. 2) Terraces and hills along the Yukon River. The majority of this area has been burned in historic fires. Post-fire seral vegetation of shrubs, deciduous and mixed forests, and post-fire black spruce dominate. Late-seral spruce cover types cover relatively small areas (Upland Spruce Forest 4%, and Subalpine Spruce Woodland 7%). 3) Mountains in the upper Charley River region, which covers most of the southern third of the Preserve, and the Ogilvie Mountains in the northeast. Historical fires cover little of this region, and most of the Preserve's old-growth spruce forests occur here (Subalpine Spruce forest 19%, Upland Spruce Forest 3%), along with alpine vegetation.

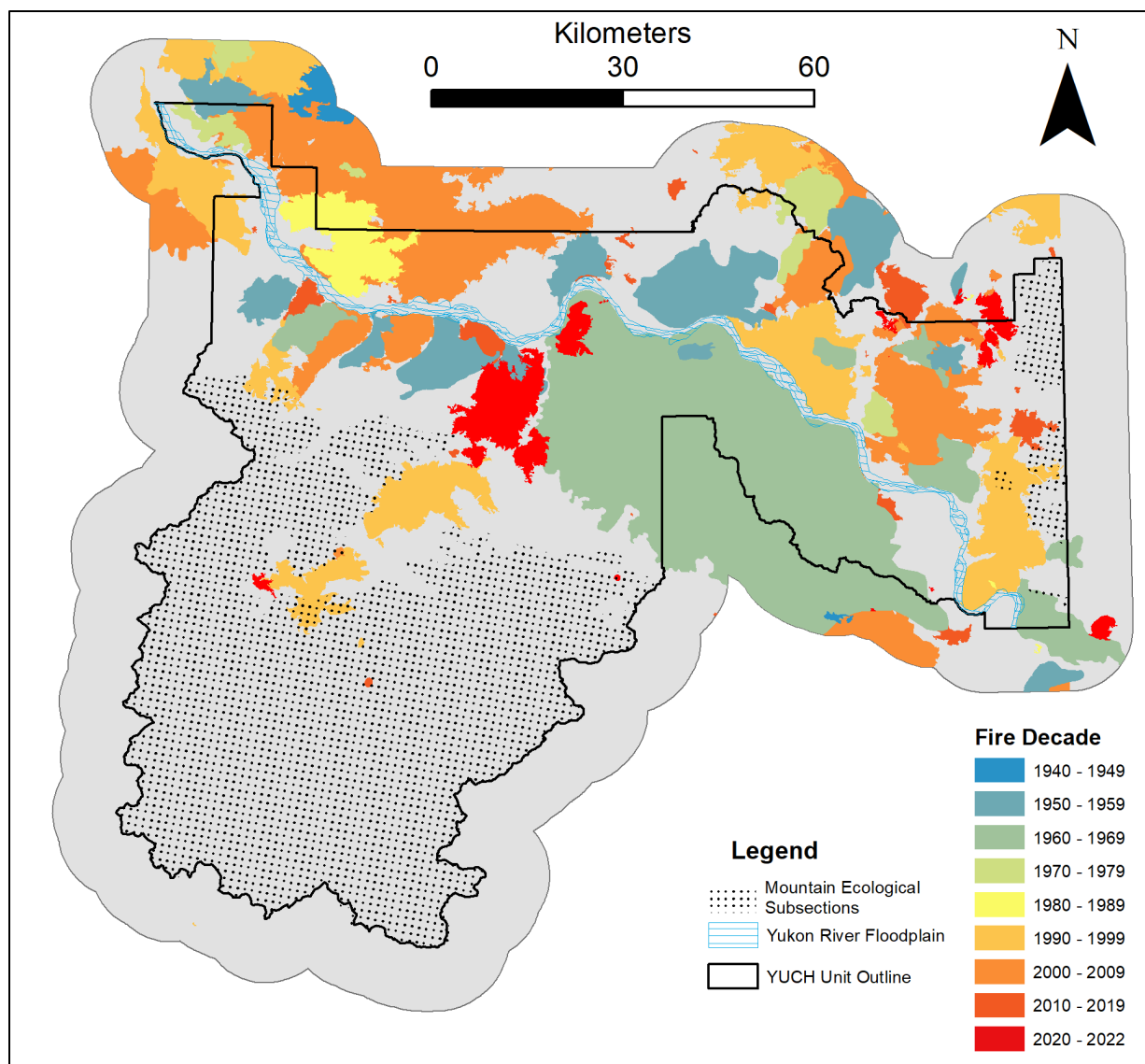


Figure 9. Location of historical fire perimeters in relation to mountainous areas and the Yukon River floodplain, as outlined by ecological subsections (Swanson 1999).

Table 8. Area of land cover types by major landform zones.

Zone ^A	Cover Type Number ^B	Area (km ²)	Area (percent of zone ^C)	Cover Type Name
Yukon River Floodplain	3	35	25	RiparianBarrens
	5	18	13	RiparianLowShrub&Herb
	7	17	12	RiparianYoungPoplarForest
	9	15	10	RiparianMixedForest
	25	13	9	BlackSpruceForest
	8	11	8	RiparianPoplarForest
	10	10	7	RiparianWhiteSpruce&Alder
	11	8	5	RiparianWhiteSpruceForest
	6	7	5	RiparianTallShrub
	23	4	3	BlackSpruceWoodland
Hills	25	843	15	BlackSpruceForest
	23	803	14	BlackSpruceWoodland
	35	631	11	MixedForestShort
	31	544	9	TallShrubSeral
	32	421	7	DeciduousForestShort
	68	389	7	SubalpineSpruceWoodland
	54	356	6	SpruceWoodland&ShrubNorth
	22	306	5	WetlandLowShrub
	38	241	4	UplandSpruceForest
	53	166	3	UplandLowShrub
	50	156	3	Burned2021-2022
	33	152	3	DeciduousOpenForest&Woodland
	37	138	2	MixedForest
	52	93	2	UplandLowWillow
Mountains	62	1019	25	AlpineDwarfShrub
	64	824	20	AlpineLowShrub
	68	785	19	SubalpineSpruceWoodland
	60	575	14	AcidicBarrens
	22	228	6	WetlandLowShrub
	38	141	3	UplandSpruceForest
	23	128	3	BlackSpruceWoodland
	63	106	3	AlpineSedge&DwarfShrub

^A Zones defined by aggregations of ecological subsections (Swanson 1999)

^B Land Cover Type numbers and names defined in Table 3

^C Only types that represent more than 1% of their zone are listed.

Training Data Accuracy Check

Recall that the mapping method used here, based on the 2nd nearest neighbor, automatically provides an opportunity for an accuracy assessment by the leave-one-out method, because each pixel with a training point is actually classified using all other training points except its own (see the Methods). A cross-tabulation of training point types assigned by image interpretation (“train”) vs. the types as extracted from the final map (“map”) shows good agreement (Tables 9 and 10): 95% of the points fall along the diagonal, indicating agreement between the two. The table is split in half vertically to fit on a page; the “producer’s accuracy” is shown along the bottom of both halves while the “user’s accuracy” is along the right side of the 2nd part of the table. These two accuracy measures differ because they are percentages based on column or row sums, respectively. Producer’s accuracy indicates percent correct relative to the known number of points of each class in the training set, while the User’s accuracy indicates the percent correct relative to the number of points that were mapped as that class. As implied by the name, User’s accuracy is generally more useful to users, because it estimates the percent of points that a user might choose on the ground and find to be correctly mapped. Producer’s accuracy is helpful to the map maker in locating types with problematic training data.

The classification matrix reveals some confusion between types 9, 10, and 11 (Riparian mixed forest, Riparian Open White Spruce & Alder, and Riparian White Spruce Forest, respectively). Type 9 had the worst User’s Accuracy of any type at 81%. These three riparian forest types grade into one another, and confusion is to be expected, both in image interpretation of the training points and operation of the classification algorithm. Another problem is the distinction of types 22 and 23 (Wetland Low Shrub and Black Spruce Woodland). These two types also grade into one another, with the only distinction being more or less than 10% tree cover. Again this distinction is quite difficult, both because it is difficult to see the stunted trees typical of these types and judge their cover (even on high-resolution imagery, 0.5 to 1 m in my case), and because the effect of these low tree covers on reflectance is very subtle and difficult for the classification algorithm to distinguish. Most of type 23’s low User’s Accuracy (83%) is due to confusion with type 22 Wetland Low Shrub and other similar types (type 24 LichenLowShrub&Woodland, which differs mainly in ground cover composition; and type 25 BlackSpruceForest, which differs mainly in tree percent cover). Another difficult distinction was between types 62 and 63 (Alpine Dwarf Shrub vs. Alpine Sedge & Dwarf Shrub). These again are types that grade into one another.

While 95% of the points were mapped in agreement with their interpreted identification, a better User’s accuracy number would be to weight the User’s accuracies by the proportion of the study area occupied by each type (according to the final map). This analysis lowers to estimated overall User’s accuracy to 93%, mainly because of the large area occupied by type 23 and its relatively low User’s accuracy (see above).

Table 9. Classification matrix of training points, by the modified knn method—part one. Rows are map classes and columns original assigned classes, for class definitions see Table 3. “prod” and “user” are producer’s and user’s accuracies.

Map	Train																							
	1	2	3	4	5	6	7	8	9	10	11	21	22	23	24	25	31	32	33	34	35	36	37	38
1	129	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	1	0	1	67	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	47	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	57	4	9	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	3	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	1	0	77	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	45	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	2	0	0	0	0	0	0	1	162	6	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	1	0	0	0	0	0	0	0	12	114	3	4	1	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	2	0	3	95	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	68	0	1	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	110	1	0	5	0	1	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	35	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	52	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	76	1	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	48	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	4	0	2	73

Table 9 (continued). Classification matrix of training points, by the modified knn method—part one. Rows are map classes and columns original assigned classes, for class definitions see Table 3. “prod” and “user” are producer’s and user’s accuracies.

Map	Train																								
	1	2	3	4	5	6	7	8	9	10	11	21	22	23	24	25	31	32	33	34	35	36	37	38	
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
53	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	0	1	0	0	1	
60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
62	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	
63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
64	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	
65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	4	
69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
prod	100	95	100	97	96	90	96	100	92	84	90	88	93	91	97	93	96	98	95	100	88	90	94	94	

Table 10. Classification matrix of training points, by the modified knn method—part two. Rows are map classes and columns original assigned classes, for class definitions see Table 3. “prod” and “user” are producer’s and user’s accuracies.

Map	Train																		user
	40	41	42	50	51	52	53	54	60	61	62	63	64	65	66	67	68	69	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
5	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	88
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	94
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	81
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	88
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	99
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
22	0	0	0	0	0	0	2	0	0	0	0	0	0	0	3	0	0	0	92
23	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	83
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	95
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	99
31	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	96
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	94
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	97
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	97
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	96
37	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	94
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	90

Table 10 (continued). Classification matrix of training points, by the modified knn method—part two. Rows are map classes and columns original assigned classes, for class definitions see Table 3. “prod” and “user” are producer’s and user’s accuracies.

Map	Train																		
	40	41	42	50	51	52	53	54	60	61	62	63	64	65	66	67	68	69	user
40	37	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	92
41	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
42	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
50	0	0	0	64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
51	0	0	0	0	69	0	0	0	0	0	0	0	0	0	0	0	0	0	100
52	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	100
53	0	0	0	0	0	0	59	0	0	0	0	0	0	0	0	0	0	0	95
54	1	0	0	1	2	0	0	66	0	0	0	0	0	0	0	0	0	0	87
60	0	0	0	0	0	0	0	1	109	0	0	0	0	0	0	0	0	0	99
61	0	0	0	1	0	0	0	0	0	36	1	0	0	0	0	0	0	0	95
62	0	0	0	0	0	0	1	0	0	0	84	5	1	0	3	0	0	0	88
63	0	0	0	0	0	0	0	0	0	0	0	23	0	0	0	0	0	0	100
64	0	0	0	0	0	0	0	0	0	0	0	0	160	1	0	0	0	0	98
65	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	100
66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	45	0	0	0	100
67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	100
68	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	80	0	90
69	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	99
prod	97	88	96	96	97	93	92	99	100	100	99	82	96	95	88	100	99	97	95

Comparison with Random Forest Classification

Classification by the Random Forest method produced visually similar results (Figure 10). The two methods usually mapped the same classes in a particular area, with differences in the positioning of gradational boundaries. The Random Forest maps were generally more intricate than the Nearest Neighbor maps. There was outright agreement between the two maps on 69% of the area.

Comparison of the two maps showed the most conspicuous differences were within the masked areas, especially the burned areas, where less unburned vegetation was recognized by RF than modified knn. Another area of disagreement was in the Ogilvie Mountains, where RF mapped some acidic barrens within the alkaline mountains mask. Recall that the masked areas were treated in the RF classification as individual binary variables. The result was that any type not trained within a masked area was allowed to occur there, but in practice it had a greatly reduced probability.

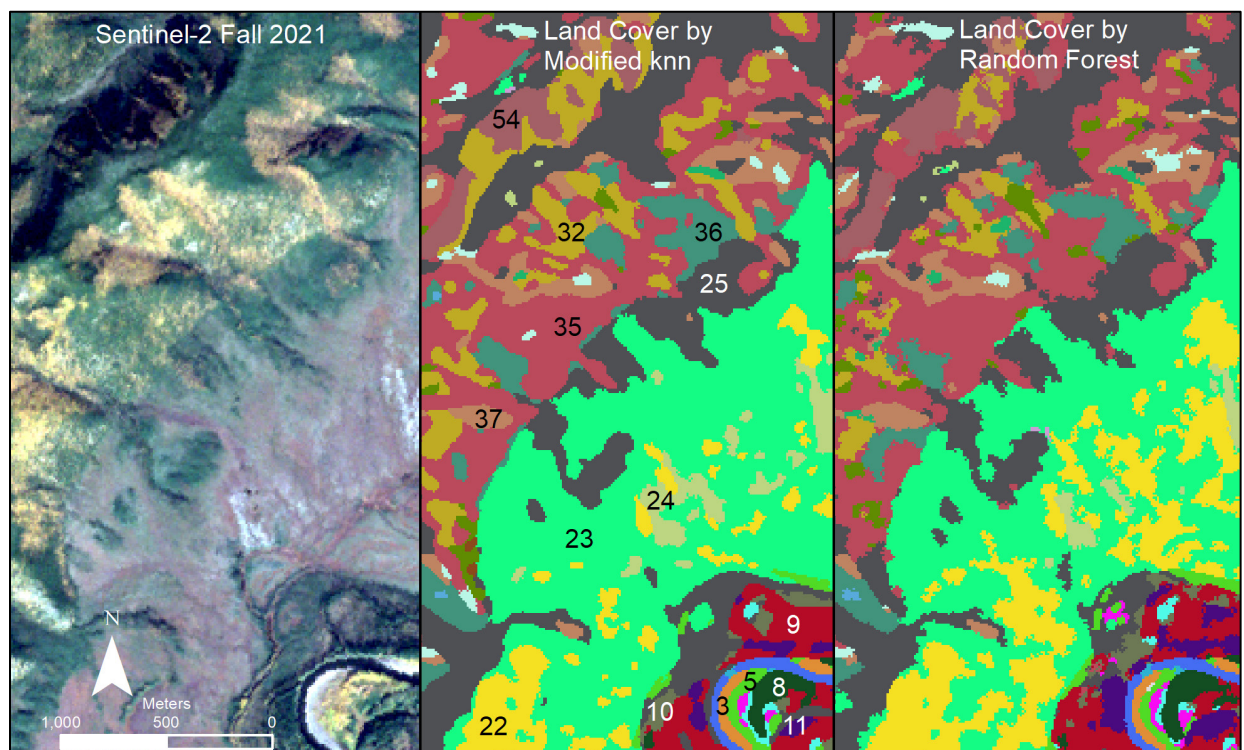


Figure 10. Comparison of maps produced by the modified knn method (center) and Random Forest (right) with the fall 2021 satellite image (left). Major types are labeled on the center image with numbers that are described in Table 3. The scene is the same as the one in Figure 6, centered near longitude 142.35°, latitude 65.44°, with the Kandik River visible in the lower right.

The Random Forest package provides two measures of the importance of each variable in the accuracy of the final map (Appendix Figure D1). The most important variables by both measures were similar and included elevation, vegetation height, and the near-infrared and red reflectance of both summer and fall.

The Random Forest “out-of-bag” cross-tabulation provides training accuracy test for that classifier (Appendix Table D1) that is analogous to the leave-one-out test for the modified knn method. The

RF classifier uses multiple random sub-samples, each with about two-thirds of the training data, to classify the remaining third. The overall accuracy estimate by RF was slightly lower than the modified nearest neighbor method (91%, not weighted by final area, or 88% when weighted by the final area).

Discussion

Vegetation Condition and Change

Vegetation change is difficult to judge by comparison of maps, because of the map errors involved. Nonetheless, the decrease in conifer forest due to fires since the 1991-based map is nearly certain, given the large area affected by fires since that time. The magnitude of the decrease, from 46% to 39% of the Preserve, is reasonable but should not be considered very precise. It is interesting to note that black-spruce dominated forest and woodland still predominate in the lowlands of burned areas, and it is apparently the drier upland areas dominated by white spruce, in the very fire-prone foothill and terrace regions of the Preserve, that have been most depleted by fires. Extensive unburned areas of white spruce still persist at higher elevations. Comparison of the old and new maps for floodplain areas suggest a possible decrease in spruce area there also, but in this case the change is less certain and would be attributed to flood destruction of forests. We are more certain that the total area of riparian vegetation vs. unvegetated Yukon River bars has changed little over the past 30 years, in contrast to what has been observed on other rivers elsewhere in Interior Alaska (Frost et al. 2023). Frost et al.'s (2023) study area included four tributary streams of the Yukon River in YUCH. The area affected in their YUCH study area was relatively small, with 7% of sample points experiencing forward transitions (i.e., succession of any kind, including colonization of barren areas) and 3% experiencing backward transitions (to an earlier seral type, such as forest eroded to barrens). It is possible that my method of differencing maps would not detect a change of a few percent, or that the Yukon River is behaving differently than these tributary streams.

Smoothing vs. Segmentation

In this study I chose to classify individual pixels obtained by smoothing the original images with a moving window method. Other studies have made vegetation maps by classification of high-resolution raster data after segmentation (Mishra and Crews 2014, Rapinel et al. 2014, Juel et al. 2015, Hampton-Miller et al. 2022). Image segmentation is the grouping of pixels into relatively homogenous regions. Data are summarized for each segment as a whole, and the segments rather than the individual pixels are classified. Advantages of classifying segments rather than individual pixels include: 1) when compared to coarse-resolution pixels, segments created from high-resolution images correspond to natural features and thus are much less likely to contain ambiguous mixtures of different cover types. For example, a large pixel that overlaps land and water may have spectral properties that resemble neither and are difficult to classify correctly, while segments aggregated from a fine-resolution image would be relatively pure. 2) Segmentation removes unwanted details. An example is a high-resolution image of a forest, where trees, tree shadows, and gaps between trees are all visible, but we are interested in classifying the forest as a whole, not these individual elements. And 3) segmentation reduces the amount of data that must be processed. For example, aggregation of pixels into even relatively small segments averaging 100 pixels each will reduce the data volume, and potentially the computational demand, by 100 times.

Segment boundaries are based on local features of the image, and usually only a subset of the available data (e.g., spectral information only), without any reference to the training data. I found it intuitively appealing to use the training data to locate boundaries, rather than relying on the “black

box” segmentation process to make these choices. My goal then was to find a method that preserved the advantages of segmentation while allowing the training data to locate boundaries. My solution was to use an edge-preserving smoother, which would summarize data over a large enough area to remove unwanted details and minimize the mixing of data across obvious boundaries (points 1 and 2 above), while allowing the classifier and training data to locate boundaries, especially gradational boundaries. This approach does not accomplish the data reduction of segmentation (point number 3 above), which means that an efficient classification algorithm must be applied.

I used a median filter here because it is inherently less prone to blur edges than a mean filter. It is also less influenced by outlier values. However, a median filter still causes some blurring of boundaries, especially of “pointed” features that are convex in plan view. The shifted median smoother applied here further prevents edge blurring, and the resulting product resembles a segmented image, but without the arbitrary hard boundaries in what are actually gradual transition zones.

Any smoothing or segmentation method results in some loss of detail, and one might ask why I chose not to simply classify individual pixels, as is traditionally done with moderate resolution image data (Landsat, 30 m). My target for the minimum size of features to be mapped was 0.5 ha, the NPS standard (Cook et al. 2016), which corresponds to 50 Sentinel-2 10-m pixels. In a forested environment, individual 10-m pixels can be dominated by single trees, tree shadows, or shrubs between trees that would be difficult to classify accurately into broad cover types. Smoothing allows us to map multi-pixel objects that follow natural boundaries. The downside is that small or narrow objects are lost, even if they are quite distinct. See the section below on “Scale Considerations” for more about what size of objects can be portrayed by the map.

Choice of Classifier: Random Forest vs. Modified knn

The Random Forest classifier has been applied with success to segmented high-resolution images (Mishra and Crews 2014, Rapinel et al. 2014, Juel et al. 2015, Hampton-Miller et al. 2022) and it also worked well on the smoothed data in my study. The Random Forest classification was simpler to apply and faster than my modified knn method, requiring just seconds to create a classification model from 2788 training points and about 1.3 hours to apply this model to classify the full 163 megapixel image. The “out-of-bag” error rate (the error in classifying the training points) was 9%, higher than the error rate of the modified knn rate of 5% but still quite good. Comparison of the two maps showed that Random Forest produced a more intricate map, perhaps because it lacked one additional smoothing step that I added to the modified knn method (median smoothing of the rasters containing distances for each pixel to individual classes, before choice of the best class).

Lacking an independent verification data set, we cannot say for certain which method is more accurate, and it is likely that this varies between cover types and regions on the map. However, the modified knn method allowed greater control over the behavior of the classifier in the masked areas, which is where the most conspicuous differences between the two maps were. Recall that any type not trained within a masked area was allowed by RF to occur there, but at a reduced probability. My manual application of masks in the modified knn method allowed me to completely exclude some types from masked areas, and leave others completely unaffected by the mask. This resulted in RF

“overmapping” some types within masked areas. For example, acidic barrens do not occur in the alkaline Ogilvie Mountains, and were excluded completely by masking in the modified knn method, but were mapped there by RF. It also results in “undermapping” of other types by RF. For example, I did not train unburned types on small remnant patches within burned areas, and thus RF nearly excluded them from burned areas, while in the modified knn method I allowed the classifier to freely compete these types with the actual burned areas within burn perimeters. I chose the modified knn map as the final product for this project, because of its slightly better appearance when compared to the original images and my preference for a classifier that is less of a “black box” and allows finer control over the result, especially by masking as just described.

The modified knn and shifted-median smoothing methods used here are promising and would benefit from more comprehensive comparative testing. A trial with modified knn and random forest, each run on both shifted median-smoothed and segmented data, and tested with independent verification data, would be especially helpful. It is likely that random forest could compete better if more extensive training data were collected, both inside and outside of every areal mask used.

Scale considerations

As mentioned previously, the NPS veg standard scale for parkwide veg mapping is 1:24,000 and 0.5 ha minimum feature (Cook et al. 2016), and I recommend using the map at about this scale (reminder: ArcGIS displays the scale on the screen). A circular 0.5 ha patch has a diameter of 80 m, so users should beware that features smaller than this will not be reliably portrayed on the map, nor will linear features narrower than 80 m wide. When viewed at 1:24,000 scale, a 0.5 ha patch is about 3 mm (1/8th inch) across, i.e., near the limit of visibility. At 10 m resolution the map is already starting to pixelate visibly when viewed at 1:24,000 scale (this corresponds to about 60 pixels per inch). Zooming further in will cause the type boundaries to be visibly controlled by arbitrary pixel boundaries and not natural features.

As discussed in the Methods, my shifting median smoother summarizes data from a 37-pixel area (3700 m² or about 0.4 ha), close to the mapping standard. My post-classification smoothing removed most single-class groups smaller than 10 pixels (1000 m², 0.1 ha), but my mapping method did not remove small patches in the 0.1 to 0.5 ha range. I chose not to use the available ArcGIS raster tools or more aggressive modal filtering (e.g., larger moving windows) that can be applied using the R “terra” package to further remove small patches on my map, because of the undesirable modifications of non-target areas that resulted.

Accuracy

This project had no independent data for accuracy assessment. I elected not to attempt to use the existing plot data for an accuracy analysis because these data were also already getting out-of-date (Table 2), and because it would have been very labor-intensive and potentially inaccurate to attempt to determine the class of the existing data according to the legend used here. Collection of accuracy data would have benefited the project but could easily have doubled the cost. If desired, verification data should be collected within the next 2 or 3 years, before the map becomes out-of-date again due to fires and vegetation growth. An objective (systematic or random) plot placement scheme should be used (Olofsson et al. 2014, Stehman and Foody 2019). For a map that is 80% accurate, the theoretical

minimum sample size is about 250 plots (Stehman 2019), though this would be only adequate for overall map accuracy and would be inadequate to determine individual class accuracies, especially for the rare types.

In an independent accuracy assessment, it would probably not be practical to sample a sufficient number of plots on the ground. Better options would be to sample by hovering at low altitude in a helicopter, or by collection and interpretation of very high resolution aerial photos, preferably in stereo so that vegetation height could be verified. Plots should be circular and 0.4 to 0.5 ha in size, to match the scale of the map (see the previous section). Plots would be classified using the key provided here (Appendix B). Revisions to the key may be required after field testing. A systematic or random plot placement scheme would result in some plots that straddle boundaries between types. In such cases the analyst should record the type for the patch 0.5 ha or greater in size to which the plot center belongs.

Bootstrap re-classification of the training data (either by leave-one-out in my modified knn method or “out-of-bag” in RF), weighted by final area of the types, suggests that the maps are quite accurate: 93% (knn) or 88% (RF). While these are helpful indicators of map accuracy, but they are probably best viewed as an upper limit of map accuracy. This is because the training data were not an objective (i.e., random or systematic) sample: my training points were chosen with a bias toward areas that I was reasonably confident of the cover type identification, and I undoubtedly avoided ambiguous areas or areas that actually are not well represented by any item in the legend. Also, a certain cover type that I identified and the classifier reliably recognized may not actually match the legend definition. For example, if some of the training points labeled “Subalpine Spruce Woodland” (defined as 10 to 25% tree cover) marked areas of greater tree cover (e.g., 30% cover), the mapping algorithm might “correctly” identify these areas as “Subalpine Spruce Woodland”, while an observer on the ground would not agree.

Furthermore, the absolute agreement of 69% between the modified knn and Random Forest maps observed here would not be possible if, as suggested by the training data accuracy estimates, both maps are about 90% accurate. If errors were randomly located, misclassified areas on both maps rarely matched (a reasonable assumption given the large number of classes), and the two maps had similar error rates, then the estimated error rate of each map would be $0.69^{0.5}$ or 83%. If, as suggested by bootstrap analysis of the training data, the modified knn map is about 5% better than the RF map, then two maps with 86% (knn) and 81% (RF) accuracy would also produce the observed 69% coincidence of types.

On the positive side, the classifier in some cases may have actually correctly identified a point that was wrongly labeled in the training data, resulting in a mismatch “error”. Given this fact and the 83% to 93% user’s accuracy estimates for the modified knn map discussed above, chances are good that the map meets the 80% NPS accuracy standard (Cook 2016). This is with 38 cover classes, of which 31 were vegetation classes. Most errors involved similar types that grade into one another, and thus the ecological consequences of the errors would be minor.

For comparison, the previous map (DU 2002) had 24 total classes, of which 17 were vegetation, and an overall accuracy of 72%. Joining similar vegetation classes into a more general legend with only 10 vegetation classes raised their accuracy to 80%.

The vegetation height layer from the digital elevation model was used as an important differentiating variable for tall shrubs (1.5 to 3 m), “short” forest (3–7 m), and tall forest (>7 m), and it is a potential source of error. The heights provided by this layer generally appeared reasonable when compared to the vegetation appearance on satellite images, though these heights clearly were imprecise. In areas with low vegetation, negative height values (which are impossible), ranging as low as –20 cm, were not unusual, suggesting a potential error of ± 20 cm. Also, the radar data used to create the vegetation height raster was collected in 2015, so in areas of actively growing vegetation the heights may actually be higher than indicated by the classes on the map. This most likely affected the rapidly growing tall shrub (1.5–3 m) and short tree (3–7 m) cover types.

Costs and Time

This project was completed with \$38,000 over two fiscal years, exclusively to cover the salary time of the author. While I did not carefully account for actual hours expended, I estimate that it exceeded the hours funded by a modest amount, no more than 25%. Some of this time was spent on tasks that probably would not need to be repeated in another project. These were: 1) developing the shifted-median smoothing and modified knn methods, and 2) creation of a summer Sentinel-2 image composite that was not ultimately used. Regarding the second task, in the 5 years prior to 11 Aug 2022 there was not a single summer date with widespread cloud-free Sentinel-2 data. In essence, all summer days with good weather in YUCH were sprinkled with cumulus clouds and their shadows. Working initially in the winter of 2021–22, I was forced to create an automated composite from all available images between June 20 2017 and August 10 2021 by taking the median of all dates for each pixel, with the majority of clouds and shadows removed. The cloud mask supplied with the images was not of sufficient quality to accomplish this, so I had to manually create masks for 57 images. The resulting composite image was satisfactory but not ideal, with numerous cloud-boundary artifacts. After classification work was well underway, the nearly Preserve-wide clear day 11 Aug 2022 allowed me to re-make a much better summer composite by manually piecing together just a few image dates.

The low cost of this project was possible thanks to extensive existing plot data, previous vegetation classification studies, and free imagery. Resources like these are available for many other park units, and thus it may be possible to replicate my process elsewhere. However, the cost would probably increase by several times to produce a map accompanied by 1) land cover type descriptions that were made specifically for the project, by analysis of existing data or new field data (as in, for example, Jorgenson et al. 2009), and 2) a comprehensive error analysis, which would probably require an extensive field effort with new plot data.

Literature Cited

- Alaska Interagency Coordination Center (AICC). 2022. “Predictive Services - Maps/Imagery/Geospatial.” 2022. <http://fire.ak.blm.gov/predsvcs/maps.php>.
- Beers, Thomas W, Peter E Dress, and Lee C Wensel. 1966. “Notes and Observations: Aspect Transformation in Site Productivity Research.” *Journal of Forestry* 64 (10): 691–92.
- Boggs, Keith, and Michelle Sturdy. 2005. “Plant Associations and Post-Fire Vegetation Succession in Yukon-Charley Rivers National Preserve.” Natural Resource Technical Report NPS/YUCH/NRTR—2005/001. Fort Collins, Colorado.
<https://irma.nps.gov/DataStore/Reference/Profile/653866>.
- Breiman, Leo. 2001. “Random Forests.” *Machine Learning* 45 (1): 5–32.
- Cook, Tammy. 2016. “NPS Vegetation Mapping Inventory Program Final Product Guidelines.” Fort Collins, Colorado: National Park Service, Inventory and Monitoring Division.
<https://irma.nps.gov/DataStore/Reference/Profile/2253594>.
- Ducks Unlimited. 2002. “Yukon-Charley/Black River/ Fortymile Earth Cover Classification.” BLM-Alaska Technical Report 48 BLM/AK/ST-02/021+6500+931. Anchorage, Alaska.
<https://irma.nps.gov/DataStore/Reference/Profile/584464>.
- European Space Agency. 2022a. “Copernicus Open Access Hub.” Copernicus Open Access Hub. 2022. <https://scihub.copernicus.eu/dhus/#/home>.
- European Space Agency. 2022b. “Sentinel-2.” Sentinel-2. 2022.
<https://sentinel.esa.int/web/sentinel/missions/sentinel-2>.
- Frost, Gerald V, Carl A Roland, and Joshua H Schmidt. 2023. “Dynamic Disequilibrium: Recent Widespread Increases in Vegetation Cover on Subarctic Floodplains of Interior Alaska.” *Ecosphere* 14 (1): e4344.
- Hampton-Miller, Celia J, Peter N Neitlich, and David K Swanson. 2022. “A High-Resolution Map of Coastal Vegetation for Two Arctic Alaskan Parklands: An Object-Oriented Approach with Point Training Data.” *PloS One* 17 (8): e0273893. <https://doi.org/10.1371/journal.pone.0273893>.
- Hijmans, Robert J. 2022. *Package “Terra”* (version R package version 1.5-21). Vienna, Austria: R Foundation for Statistical Computing. <http://CRAN.R-project.org/package=terra>.
- Jorgenson, M. Torre, J. E. Roth, P. F. Miller, M. J. Macander, M. S. Duffy, A. F. Wells, G. V. Frost, and E. R. Pullman. 2009. “An Ecological Land Survey and Landcover Map of the Arctic Network.” Natural Resource Technical Report ARCN/NRTR-2009/270. Fort Collins (CO): National Park Service. <https://irma.nps.gov/App/Reference/Profile/663934>.

- Jorgenson, M. Torre, Kenji Yoshikawa, Mikhail Kanevskiy, Yuri Shur, Vladimir Romanovsky, Sergei Marchenko, Guido Grosse, Jerry Brown, and Ben Jones. 2008. "Permafrost Characteristics of Alaska." Fairbanks, Alaska: Institute of Northern Engineering, University of Alaska Fairbanks. <https://catalog.northslopescience.org/dataset/1725>.
- Juel, Anders, Geoffrey Brian Groom, Jens-Christian Svenning, and Rasmus Ejrnæs. 2015. "Spatial Application of Random Forest Models for Fine-Scale Coastal Vegetation Classification Using Object Based Analysis of Aerial Orthophoto and DEM Data." *International Journal of Applied Earth Observation and Geoinformation* 42: 106–14. <https://doi.org/10.1016/j.jag.2015.05.008>.
- Liaw, Andy, and Matthew Wiener. 2002. "Classification and Regression by RandomForest." *R News* 2 (3): 18–22.
- McCune, Bruce, and Dylan Keon. 2002. "Equations for Potential Annual Direct Incident Radiation and Heat Load." *Journal of Vegetation Science* 13 (4): 603–6.
- Miller, Celia J H, Peter N. Neitlich, and David K. Swanson. 2020. "Coastal Vegetation Classification for Bering Land Bridge National Preserve & Cape Krusenstern National Monument." Fairbanks, Alaska: National Park Service. <https://irma.nps.gov/DataStore/Reference/Profile/2272456>.
- Mishra, Niti B, and Kelley A Crews. 2014. "Mapping Vegetation Morphology Types in a Dry Savanna Ecosystem: Integrating Hierarchical Object-Based Image Analysis with Random Forest." *International Journal of Remote Sensing* 35 (3): 1175–98.
- National Centers for Environmental Information, NCEI. 2023. "U.S. Monthly Climate Normals (1991–2020)." 2023. <https://www.ncei.noaa.gov/access/search/data-search/normals-monthly-1991-2020?dataTypes=MLY-PRCP-NORMAL&bbox=64.809,-141.224,64.767,-141.182>.
- Olofsson, Pontus, Giles M. Foody, Martin Herold, Stephen V. Stehman, Curtis E. Woodcock, and Michael A. Wulder. 2014. "Good Practices for Estimating Area and Assessing Accuracy of Land Change." *Remote Sensing of Environment* 148: 42–57. <https://doi.org/10.1016/j.rse.2014.02.015>.
- Parry, Nathan. 2013. "Soil Survey of Yukon-Charley Rivers National Preserve Area, Alaska." US Department of Agriculture, Natural Resources Conservation Service. <https://irma.nps.gov/DataStore/Reference/Profile/2206820>.
- Rapinel, Sebastien, Bernard Clément, Sylvie Magnanon, Vanessa Sellin, and Laurence Hubert-Moy. 2014. "Identification and Mapping of Natural Vegetation on a Coastal Site Using a Worldview-2 Satellite Image." *Journal of Environmental Management* 144: 236–46.
- Roland, C., K. Oakley, E. M. Debevec, and P. Loomis. 2004. "Monitoring Vegetation Structure and Composition at Multiple Spatial Scales in the Central Alaska Network." Fairbanks, Alaska: National Park Service. <https://irma.nps.gov/DataStore/Reference/Profile/2190295>.

- Schliep, Klaus, and Klaus Hechenbichler. 2016. *Kknn: Weighted k-Nearest Neighbors* (version R package version 1.3.1). Vienna, Austria: R Foundation for Statistical Computing.
<https://CRAN.R-project.org/package=kknn>.
- Stehman, Stephen V., and Giles M. Foody. 2019. “Key Issues in Rigorous Accuracy Assessment of Land Cover Products.” *Remote Sensing of Environment* 231: 111199.
<https://doi.org/10.1016/j.rse.2019.05.018>.
- Swanson, David K. 1999. “Ecological Subsections of Yukon-Charley Rivers National Preserve.” Anchorage, Alaska: Alaska Region Inventory and Monitoring Program.
<https://irma.nps.gov/DataStore/Reference/Edit/547695>.
- Swanson, Shelli A., and Debora A. Nigro. 2003. “A Breeding Landbird Inventory of Yukon-Charley Rivers National Preserve, Alaska, June 1999 and 2000.” Final Report YUCH-03-001. Fairbanks, Alaska: National Park Service. <https://irma.nps.gov/DataStore/Reference/Profile/177539>.
- U.S. Geological Survey. 2015. “IFSAR Orthorectified Radar Image (ORI) Alaska.” U.S. Department of the Interior, Geological Survey. https://lta.cr.usgs.gov/ifsar_ori.
- USGS. 2018. “USGS EROS Archive - Digital Elevation - Interferometric Synthetic Aperture Radar (IFSAR) - Alaska.” https://www.usgs.gov/centers/eros/science/usgs-eros-archive-digital-elevation-interferometric-synthetic-aperture-radar?qt-science_center_objects=0#qt-science_center_objects.
- USNVC. 2023. “USNVC (United States National Vegetation Classification) Database Version 2.04. Federal Geographic Data Committee, Vegetation Subcommittee. Washington D.C.” 2023.
<https://usnvc.org/explore-classification/>.
- Viereck, Leslie A., C. T. Dyrness, A. R. Batten, and K. J. Wenzlick. 1992. “The Alaska Vegetation Classification.” General Technical Report PNW-GTR-286. Portland, Oregon: USDA Forest Service, Pacific Northwest Research Station.
http://www.fs.fed.us/pnw/publications/pnw_gtr286/.
- Wong, Tzu-Tsung. 2015. “Performance Evaluation of Classification Algorithms by K-Fold and Leave-One-out Cross Validation.” *Pattern Recognition* 48 (9): 2839–46.

Appendix A: Additional Classification Data

Table A1. Polygon masks used in land cover type classification.

Cover Type Number	Cover Type Name	Location ^A	Mask ^B
1	Water	–	none
2	AquaticVegetation	–	none
3	RiparianBarrens	out	Tailings
3	RiparianBarrens	in	Riparian
4	MineTailingBarrens	in	Tailings
5	RiparianLowShrub&Herb	in	Riparian
6	RiparianTallShrub	in	Riparian
7	RiparianYoungPoplarForest	in	Riparian
8	RiparianPoplarForest	in	Riparian
9	RiparianMixedForest	in	Riparian
10	RiparianWhiteSpruce&Alder	in	Riparian
11	RiparianWhiteSpruceForest	in	Riparian
21	WetHerb&Moss	out	Fires 2021-2022
22	WetlandLowShrub	–	none
23	BlackSpruceWoodland	–	none
24	LichenLowShrub&Woodland	out	Riparian
25	BlackSpruceForest	–	none
31	TallShrubSeral	out	Riparian
32	DeciduousForestShort	out	Riparian
33	DeciduousOpenForest&Woodland	out	Riparian
34	DeciduousForest	out	Riparian
35	MixedForestShort	out	Riparian
36	MixedOpenForest&Woodland	out	Riparian
37	MixedForest	out	Riparian
38	UplandSpruceForest	–	none
40	BluffBarrens	out	Ogilvie Mtns
41	DryHerbaceous	–	none
42	DryLowShrub	–	none
50	Burned2021-2022	in	Fires 2021-2022
51	LowShrub&HerbBurned2015-2020	in	Fires 2015-2020
52	UplandLowWillow	out	Riparian

^A "in" means that the cover type was restricted to occur only inside of the masking polygons, "out" that it was restricted to occur only outside of the masking polygons

^B "None" indicates that the type was not masked, i.e., was allowed to occur anywhere in the Preserve

Table A1 (continued). Polygon masks used in land cover type classification.

Cover Type Number	Cover Type Name	Location ^A	Mask ^B
53	UplandLowShrub	out	Riparian
54	SpruceWoodland&ShrubNorth	–	none
60	AcidicBarrens	out	Ogilvie Mtns
61	AlkalineBarrens	in	Ogilvie Mtns
62	AlpineDwarfShrub	out	Fires 2021-2022
63	AlpineSedge&DwarfShrub	–	none
64	AlpineLowShrub	–	none
65	SubalpineTallShrub	–	none
66	TussockTundra	–	none
67	LichenTundra	in	Snowy Domes Subsection
68	SubalpineSpruceWoodland	–	none
69	SubalpineSpruceLichenWoodland	out	Fires 2001-2022

^A "in" means that the cover type was restricted to occur only inside of the masking polygons, "out" that it was restricted to occur only outside of the masking polygons

^B "None" indicates that the type was not masked, i.e., was allowed to occur anywhere in the Preserve

Appendix B: Key to the Land Cover Classes

General

1a. Water, floating aquatic vegetation, or emergent vegetation in water. **2**

1b. Land, with or without vegetation. **3**

2a. Aquatic vegetation (floating or emergent) with >10% cover. **Type 2: Aquatic Vegetation**

2b. Aquatic vegetation absent or inconspicuous. **Type 1: Water**

3a. Vegetation cover >10%. **4** (vegetation)

3b. Vegetation cover, excluding crustose lichens on rock is <10%, or vegetation not visible in images due to terrain shadow. **6** (barrens)

4a. Trees taller than 3 m have >10% cover, or black spruce (*Picea mariana*) <3 m tall forms the overstory with >10% cover. **10** (Forest, woodland, and spruce dwarf tree scrub)

4b. Vegetation taller than 3 m tall has <10% cover, and black spruce does not form the overstory with >10% cover. **5**

5a. Shrub cover >25%. **40** (Shrub vegetation)

5b. Shrub cover <25%. **60** (Herbaceous vegetation)

Barrens and Sparse Vegetation

6a. Nearly level, frequently flooded barrens along rivers. **Type 3: Riparian Barrens**

6b. Mine tailings. **Type 4: Mine Tailings Barrens**

6c. Steep areas adjacent to rivers, below elevational treeline, mostly below 3000 ft (900 m). **Type 40: Bluff Barrens**

6d. Barrens in alpine areas on non-calcareous bedrock, mostly above 3000 ft (900 m). **Type 60: Acidic Barrens**

6e. Barrens in alpine areas on calcareous bedrock, mostly above 3000 ft (900 m) in the Ogilvie Mountains, north of the Yukon River. **Type 61: Alkaline Barrens**

6f. Surface blackened by fire; standing and fallen vegetation dead and charred. Areas burned in 2021 or 2022: **Type 50: Burned 2021-2022**

6g. Terrain shadow below 3000 ft; slopes less than 40° and presumed to be vegetated. **Type 54: Spruce Woodland and Shrub North**

Forest Vegetation

10a. More than 75% of the tree cover is evergreen conifers. **11** (Coniferous Forest)

10b. The proportion of tree canopy cover is 25% to 75% of both evergreen conifers and broadleaf deciduous trees. **20** (Mixed Forest)

10c. More than 75% of the tree cover is broadleaf deciduous trees. **30** (Deciduous Forest)

Coniferous Forest

11a. Forest is in a riparian zone that is flooded at least occasionally (at least 5 out of 100 years). White spruce is usually the dominant conifer. **12**

11b. Forest is not flooded and not in a riparian zone. **13**

12a. Open spruce forest; alder cover >25% and shrubs are clearly visible in gaps between trees from the air. **Type 10: Riparian White Spruce & Alder**

12b. Spruce forest, with alder cover <25% or understory is obscured by trees and tree shadows (tree cover usually >40%). **Type 11: Riparian White Spruce Forest**

13a. Black spruce is usually the dominant tree species. Mature trees are rarely more than 30 cm in diameter. Indicators of wetness are usually present: *Sphagnum* sp., *Aulocomnium* sp. *Eriophorum vaginatum*, soil organic or fine-grained and often saturated with water. **14**

13c. White spruce is usually the dominant tree species. Wetness indicators absent. **17**

14a. Tree cover <25%. **15 (Black Spruce Woodlands)**

14b. Tree cover >25%. **Type 25: Black Spruce Forest**

15a. Landform is flat, or concave and gently sloping (<10°). **17**

15b. Slope north-facing and usually >20°. **Type 54: Spruce Woodland & Shrub North**

16a. Ground layer dominated by moss. **Type 23: Black Spruce Woodland**

16b. Ground layer dominated by lichens. **Type 24: Lichen Low Shrub and Woodland**

17a. Tree cover >25%. **Type 38: Upland Spruce Forest**

17b. Tree cover <25%; elevation usually above 900 m. **18**

18a. Ground layer dominated by moss or plant litter. **Type 68: Subalpine spruce woodland**

18b. Ground layer dominated by lichens. **Type 69: Subalpine spruce lichen woodland**

Mixed Forest

20a. Forest is in a riparian zone that is flooded at least occasionally (at least 5 out of 100 years). White spruce is usually the dominant conifer and balsam poplar is usually the dominant broadleaf tree. **Type 9: Riparian Mixed Forest**

20b. Forest is not in a riparian zone and not flooded; birch or aspen are usually the dominant broadleaf trees. **21**

21a. Tree cover less than 50%. Trees are mostly aspen and white spruce, with lesser amounts of birch. On south-facing slopes, slope steepness usually greater 20°. **Type 36: Mixed Open Forest and Woodland**

21b. Tree cover >25% and not on steep, south-facing slopes. Mainly white spruce and paper birch, less commonly black spruce or aspen. **22**

22a. Trees 3 to 7 m tall. **Type 35: Mixed Forest Short**

22b. Trees more than 7 m tall. **Type 37: Mixed Forest**

Deciduous Forest

30a. Forest is in a riparian zone that is flooded at least occasionally (at least 5 out of 100 years). Balsam poplar is usually the dominant species. **31**

30b. Forest is not in a riparian zone and not flooded; birch or aspen are usually the dominant broadleaf trees. **32**

31a. Trees are 3 to 7 m tall. **Type 7: Riparian Young Poplar Forest**

31b. Trees are more than 7 m tall: **Type 8: Riparian Poplar Forest**

32a. Tree cover less than 50%. Trees are mostly aspen with less amounts of poplar or birch. On south-facing slopes, slope steepness usually greater 20°. **Type 33: Deciduous Open Forest and Woodland**

32b. Tree cover >25% and not on steep, south-facing slopes. Mainly paper birch, locally aspen. **33**

33a. Trees 3 to 7 m tall. **Type 32: Deciduous Forest Short**

33b. Trees more than 7 m tall. **Type 34: Deciduous Forest**

Shrub Vegetation

40a. Shrubs 1.5 to 3 m tall. **41** (tall shrub vegetation)

40b. Shrubs 0.2 to 1.5 m tall. **43** (low shrub vegetation)

40c. Shrubs <0.2 m tall. **50** (dwarf shrub vegetation)

Tall Shrub Vegetation

41a. Location is in a riparian zone that is flooded at least occasionally (at least 5 out of 100 years).

Type 6: Riparian Tall Shrub

41b. Location is not in a riparian zone and not flooded. **42**

42a. Shrubs are seral to forest after disturbance (usually fire); may include alder (*Alnus*) and willow (*Salix*) shrubs, and small trees, generally below 800 m elevation. **Type 31: Tall Shrub seral**

42b. Shrubs are not obviously seral to forest, usually above 700 m elevation. **Type 65: Subalpine Tall Shrub**

Low Shrub Vegetation

43a. Location is in a riparian zone that is flooded at least occasionally (at least 5 out of 100 years).

Type 5: Riparian Low Shrub and Herbs

43b. Location is not in a riparian zone and not flooded. **44**

44a. Shrub cover less than 50% and consisting of resprouting species after fires in 2015 to 2020.

Type 51: LowShrub&HerbBurned2015-2020

44b. Not in areas with shrubs resprouting after fires in 2015 to 2020. **45**

45a. Indicators of wetness are usually present: *Sphagnum* sp., *Aulocomnium* sp., *Eriophorum vaginatum*, soil organic or fine-grained and often saturated with water. **46**

45b. Indicators of wetness usually absent or uncommon. Landform usually convex or steeply sloping. **48**

46a. Landform is flat or concave and gently sloping, less than 10°. **47**

46b. Slope north-facing and usually >20°. **Type 54: Spruce Woodland & Shrub North**

47a. Ground cover dominated by mosses. **Type 22: Wetland Low Shrub**

47b. Ground cover dominated by lichens. **Type 24: Lichen Low Shrub & Woodland**

48a. Slope steep ($>20^\circ$) and south-facing. Elevation below 700 m. Trees absent due to dryness. **Type 42: Dry Low Shrub**

48b. Alpine and subalpine areas above 700 m elevation and above treeline. Trees absent due to cold climate. **Type 64: Alpine Low Shrub**

48c. Vegetation is seral to forest after disturbance, usually fire. **49**

49a. Canopy dominated by willows. **Type 52: Upland Low Willow**

49b. Canopy dominated by shrub birch, or ericaceous shrubs (Labrador Tea, blueberry): **Type 53 Upland Low Shrub**

Dwarf Shrub Vegetation

50a. Sedges and grasses equal to or exceed dwarf shrub cover. **Type 63: Sedge & Dwarf Shrub**

50b. Dwarf shrub cover exceeds graminoid cover. **Type 62: Alpine Dwarf Shrub**

Herbaceous Vegetation

60a. In depressions or along shore of ponds and lakes, with water table usually near the surface. Ground cover of herbaceous litter or moss. Slope is flat and smooth, without microtopography of tussocks or hummocks. **Type 21: Wet Herb & Moss**

60b. On dry or mesic slopes; *or* nearly level and in riparian areas that are flooded at least occasionally (at least 5 out of 100 years) by flowing river water that does not persist after the flood recedes; *or* in nearly level areas that are wet but standing water is present only in micro-depressions between tussocks. **61**

61a. In riparian areas flooded at least occasionally. **Type 5: Riparian Low Shrub and Herbs**

61b. Not in riparian areas. **62**

62a. Foliose and fruticose lichen cover more than 25% and exceed moss cover; in alpine areas, above 800 m elevation. **Type 67: Lichen Tundra**

62b. Ground cover dominated by moss, litter, or bare ground and rock. **63**

63a: Indicators of wetness are present: *Sphagnum* sp., *Aulocomnium* sp., *Eriophorum vaginatum*, soil organic or fine-grained and often saturated with water. Microtopography of tussocks or moss hummocks present. **Type 66: Tussock Tundra**

63b. Indicators of wetness absent; tussocks and moss hummocks absent. **64**

64a. Slopes generally $>20^\circ$ and south-facing. Woody vegetation limited by dry conditions and unstable slopes. Mostly below 800 m elevation. **Type 41: Dry Herbaceous**

64b. Slopes gentler or not south-facing. Herbaceous vegetation is seral to forest after fire in 2015 to 2020: **Type 51: Low Shrub & Herb Burned 2015-2020**

64c. In alpine areas above 1000 m. Woody vegetation limited to dwarf shrubs by cold climate. **Type 63: Sedge & Dwarf Shrub**

Appendix C: Tables relating the map legend to other classifications

Table C1. Plant associations (Boggs and Sturdy 2005) of the land cover types.

Cover Type Number	Cover Type Name	Plant Association	Page ^A
1	Water	–	–
2	AquaticVegetation	–	–
3	RiparianBarrens	–	–
4	MineTailingBarrens	–	–
5	RiparianLowShrub&Herb	Salix alaxensis Floodplain	129
6	RiparianTallShrub	Young Populus balsamifera Floodplain	91
6	RiparianTallShrub	Alnus viridis ssp. crispa Floodplain	107
6	RiparianTallShrub	Salix alaxensis Floodplain	129
7	RiparianYoungPoplarForest	Young Populus balsamifera Floodplain	91
8	RiparianPoplarForest	Populus balsamifera / Alnus viridis ssp. crispa Floodplain	85
9	RiparianMixedForest	–	–
10	RiparianWhiteSpruce&Alder	Picea glauca / Alnus viridis ssp. crispa Floodplain	45
11	RiparianWhiteSpruceForest	Picea glauca / Rosa acicularis	51
21	WetHerb&Moss	Myrica gale	127
21	WetHerb&Moss	Carex aquatilis	158
21	WetHerb&Moss	Carex rostrata	161
22	WetlandLowShrub	Alnus viridis ssp. crispa / Eriophorum vaginatum	105
22	WetlandLowShrub	Betula nana / Carex bigelowii	114
22	WetlandLowShrub	Ledum palustre ssp. decumbens	119
22	WetlandLowShrub	Ledum palustre ssp. decumbens / Eriophorum vaginatum	121
22	WetlandLowShrub	Vaccinium uliginosum / Carex bigelowii	135
22	WetlandLowShrub	Ledum palustre ssp. decumbens - Vaccinium uliginosum - Eriophorum vaginatum	150
23	BlackSpruceWoodland	Dwarf Picea mariana / Betula nana	59
23	BlackSpruceWoodland	Dwarf Picea mariana / Betula nana - Carex bigelowii	61
23	BlackSpruceWoodland	Dwarf Picea mariana / Betula nana - Eriophorum vaginatum	63
23	BlackSpruceWoodland	Dwarf Picea mariana / Carex lugens	65
23	BlackSpruceWoodland	Dwarf Picea mariana / Eriophorum vaginatum	67

^A Page number in Boggs and Sturdy (2005) where the association is described.

Table C1 (continued). Plant associations (Boggs and Sturdy 2005) of the land cover types.

Cover Type Number	Cover Type Name	Plant Association	Page ^A
23	BlackSpruceWoodland	Dwarf Picea mariana / Ledum palustre ssp. decumbens	69
23	BlackSpruceWoodland	Dwarf Picea mariana / Vaccinium vitis-idaea	71
23	BlackSpruceWoodland	Picea mariana / Alnus viridis ssp. crispa	73
23	BlackSpruceWoodland	Picea mariana / Betula nana	75
23	BlackSpruceWoodland	Picea mariana / Bryophyte	77
23	BlackSpruceWoodland	Picea mariana / Ledum palustre ssp. decumbens	79
24	LichenLowShrub&Woodland	Dwarf Picea mariana / Betula nana	59
24	LichenLowShrub&Woodland	Picea mariana / Bryophyte	77
24	LichenLowShrub&Woodland	Ledum palustre ssp. decumbens	119
25	BlackSpruceForest	Dwarf Picea mariana / Betula nana - Carex bigelowii	61
25	BlackSpruceForest	Dwarf Picea mariana / Betula nana - Eriophorum vaginatum	63
25	BlackSpruceForest	Dwarf Picea mariana / Eriophorum vaginatum	67
25	BlackSpruceForest	Dwarf Picea mariana / Ledum palustre ssp. decumbens	69
25	BlackSpruceForest	Dwarf Picea mariana / Vaccinium vitis-idaea	71
25	BlackSpruceForest	Picea mariana / Alnus viridis ssp. crispa	73
25	BlackSpruceForest	Picea mariana / Betula nana	75
25	BlackSpruceForest	Picea mariana / Ledum palustre ssp. decumbens	79
25	BlackSpruceForest	Picea glauca - Picea mariana / Vaccinium uliginosum	81
31	TallShrubSeral	Young Betula papyrifera	89
31	TallShrubSeral	Salix alaxensis Sideslope	131
32	DeciduousForestShort	Young Betula papyrifera	89
32	DeciduousForestShort	Young Populus tremuloides	93
33	DeciduousOpenForest&Woodland	Populus tremuloides / Rosa acicularis	87
33	DeciduousOpenForest&Woodland	Young Populus tremuloides	93
34	DeciduousForest	Betula papyrifera / Rosa acicularis	83
35	MixedForestShort	Young Picea glauca - Betula papyrifera	101
35	MixedForestShort	Young Picea mariana - Betula papyrifera	103
36	MixedOpenForest&Woodland	Picea glauca - Populus tremuloides	97
37	MixedForest	Picea glauca - Betula papyrifera / Rosa acicularis	95
37	MixedForest	Picea mariana - Betula papyrifera / Alnus viridis ssp. Crispa	99
38	UplandSpruceForest	Picea glauca / Betula nana / Carex bigelowii	47
38	UplandSpruceForest	Picea glauca / Bryophyte	49

^A Page number in Boggs and Sturdy (2005) where the association is described.

Table C1 (continued). Plant associations (Boggs and Sturdy 2005) of the land cover types.

Cover Type Number	Cover Type Name	Plant Association	Page ^A
38	UplandSpruceForest	<i>Picea glauca</i> / <i>Vaccinium uliginosum</i>	55
38	UplandSpruceForest	<i>Picea glauca</i> - <i>Picea mariana</i> / <i>Vaccinium uliginosum</i>	81
40	BluffBarrens	–	–
41	DryHerbaceous	<i>Artemisia frigida</i> - <i>Calamagrostis purpurascens</i> - <i>Pseudoroegneria spicata</i> ssp. <i>spicata</i>	111
41	DryHerbaceous	<i>Artemisia alaskana</i>	153
41	DryHerbaceous	<i>Calamagrostis purpurascens</i>	157
41	DryHerbaceous	<i>Festuca altaica</i> / <i>Calamagrostis</i> species	165
42	DryLowShrub	Young <i>Populus tremuloides</i>	93
42	DryLowShrub	<i>Amelanchier alnifolia</i>	109
42	DryLowShrub	<i>Artemisia frigida</i>	110
42	DryLowShrub	<i>Juniperus communis</i>	118
50	Burned2021-2022	–	–
51	LowShrub&HerbBurned2015-2020	<i>Ledum groenlandicum</i>	125
51	LowShrub&HerbBurned2015-2020	<i>Bromus inermis</i> var. <i>arcticus</i>	154
51	LowShrub&HerbBurned2015-2020	<i>Calamagrostis canadensis</i>	156
51	LowShrub&HerbBurned2015-2020	<i>Chamerion angustifolium</i> ssp. <i>angustifolium</i>	162
52	UplandLowWillow	<i>Salix pulchra</i> - <i>Betula nana</i>	133
53	UplandLowShrub	<i>Betula nana</i> - <i>Ledum palustre</i> ssp. <i>decumbens</i> - <i>Vaccinium uliginosum</i>	116
53	UplandLowShrub	<i>Ledum palustre</i> ssp. <i>decumbens</i>	119
53	UplandLowShrub	<i>Ledum palustre</i> ssp. <i>decumbens</i> - <i>Vaccinium uliginosum</i>	123
54	SpruceWoodland&ShrubNorth	<i>Picea mariana</i> / <i>Alnus viridis</i> ssp. <i>crispa</i>	73
54	SpruceWoodland&ShrubNorth	<i>Picea glauca</i> - <i>Picea mariana</i> / <i>Vaccinium uliginosum</i>	81
54	SpruceWoodland&ShrubNorth	<i>Betula nana</i> - <i>Ledum palustre</i> ssp. <i>decumbens</i> - <i>Vaccinium uliginosum</i>	116
60	AcidicBarrens	–	–
61	AlkalineBarrens	–	–
62	AlpineDwarfShrub	<i>Arctostaphylus rubra</i>	137
62	AlpineDwarfShrub	<i>Cassiope tetragona</i>	140
62	AlpineDwarfShrub	<i>Dryas integrifolia</i>	141
62	AlpineDwarfShrub	<i>Dryas octopetala</i>	143
62	AlpineDwarfShrub	<i>Dryas octopetala</i> / <i>Carex stylosa</i>	144
62	AlpineDwarfShrub	<i>Dryas octopetala</i> - <i>Cassiope tetragona</i>	146
62	AlpineDwarfShrub	<i>Empetrum nigrum</i> - <i>Vaccinium vitis-idaea</i>	148

^A Page number in Boggs and Sturdy (2005) where the association is described.

Table C1 (continued). Plant associations (Boggs and Sturdy 2005) of the land cover types.

Cover Type Number	Cover Type Name	Plant Association	Page ^A
63	AlpineSedge&DwarfShrub	Dryas octopetala / Carex stylosa	144
63	AlpineSedge&DwarfShrub	Carex bigelowii	159
64	AlpineLowShrub	Betula nana	112
64	AlpineLowShrub	Betula nana / Carex bigelowii	114
64	AlpineLowShrub	Betula nana - Ledum palustre ssp. decumbens - Vaccinium uliginosum	116
64	AlpineLowShrub	Salix pulchra - Betula nana	133
64	AlpineLowShrub	Vaccinium uliginosum / Carex bigelowii	135
64	AlpineLowShrub	Betula nana - Vaccinium uliginosum - Carex bigelowii	138
64	AlpineLowShrub	Salix pulchra	152
65	SubalpineTallShrub	Alnus viridis ssp. crispa / Eriophorum vaginatum	105
65	SubalpineTallShrub	Salix alaxensis Sideslope	131
66	TussockTundra	Ledum palustre ssp. decumbens - Vaccinium uliginosum - Eriophorum vaginatum	150
66	TussockTundra	Eriophorum vaginatum	163
67	LichenTundra	Betula nana	112
67	LichenTundra	Carex bigelowii	159
68	SubalpineSpruceWoodland	Picea glauca / Salix species / Carex bigelowii	53
68	SubalpineSpruceWoodland	Woodland Picea glauca / Betula nana	57
69	SubalpineSpruceLichenWoodland	Picea glauca / Bryophyte	49
69	SubalpineSpruceLichenWoodland	Woodland Picea glauca / Betula nana	57

^A Page number in Boggs and Sturdy (2005) where the association is described.

Table C2. USDA-NRCS ecosites of the land cover types. Ecosites are described in Parry (2013); page numbers are indicated in this table.

Cover Type Number	Cover Type Name	Ecosite	Phase	Ecosite Name	Page
1	Water	—	—	—	—
2	AquaticVegetation	—	—	—	—
3	RiparianBarrens	R231XY126AK	1.1 (HCPC)	Boreal Gravelly Floodplain Non-Vegetated	661
4	MineTailingBarrens	—	—	—	—
5	RiparianLowShrub&Herb	F231XY130AK	1.3 (2AE)	Populus balsamifera/Salix alaxensis/Calamagrostis canadensis	241
5	RiparianLowShrub&Herb	F231XY196AK	1.4 (1CB)	Picea glauca	535
5	RiparianLowShrub&Herb	R231XY152AK	1.1 (HCPC)	Subalpine Scrub Loamy Drainages	764
5	RiparianLowShrub&Herb	R231XY152AK	1.2 (2AE)	Subalpine Scrub Loamy Drainages	764
5	RiparianLowShrub&Herb	R231XY198AK	1.3 (2AE)	Boreal Scrub Sandy Floodplain Low	812
6	RiparianTallShrub	F231XY130AK	1.2 (2AM)	Populus balsamifera/Salix alaxensis/Calamagrostis canadensis	241
6	RiparianTallShrub	R231XY195AK	1.1 (HCPC)	Boreal Scrub Gravelly Drainages	798
6	RiparianTallShrub	R231XY195AK	1.2 (2FL)	Boreal Scrub Gravelly Drainages	798
6	RiparianTallShrub	R231XY198AK	1.1 (HCPC)	Boreal Scrub Sandy Floodplain Low	812
6	RiparianTallShrub	R231XY198AK	1.2 (2AM)	Boreal Scrub Sandy Floodplain Low	812
7	RiparianYoungPoplarForest	F231XY130AK	1.1 (HCPC)	Populus balsamifera/Salix alaxensis/Calamagrostis canadensis	241
7	RiparianYoungPoplarForest	F231XY189AK	1.3 (2AE)	Populus balsamifera-Picea glauca/Alnus incana ssp. tenuifolia-Salix alaxensis/Equisetum arvense-Mertensia paniculata	475

Table C2 (continued). USDA-NRCS ecosites of the land cover types. Ecosites are described in Parry (2013); page numbers are indicated in this table.

Cover Type Number	Cover Type Name	Ecosite	Phase	Ecosite Name	Page
8	RiparianPoplarForest	F231XY189AK	1.2 (2AM)	Populus balsamifera-Picea glauca/Alnus incana ssp. tenuifolia-Salix alaxensis/Equisetum arvense-Mertensia paniculata	475
9	RiparianMixedForest	F231XY131AK	1.3 (2AE)	Picea glauca/Rosa acicularis/Lupinus arcticus	256
9	RiparianMixedForest	F231XY151AK	1.2 (2AL)	Picea glauca/Alnus viridis ssp. fruticosa	302
9	RiparianMixedForest	F231XY151AK	1.3 (2AE)	Picea glauca/Alnus viridis ssp. fruticosa	302
9	RiparianMixedForest	F231XY189AK	1.1 (HCPC)	Populus balsamifera-Picea glauca/Alnus incana ssp. tenuifolia-Salix alaxensis/Equisetum arvense-Mertensia paniculata	475
9	RiparianMixedForest	F231XY196AK	1.3 (2AE)	Picea glauca	535
10	RiparianWhiteSpruce&Alder	F231XY151AK	1.1 (HCPC)	Picea glauca/Alnus viridis ssp. fruticosa	302
10	RiparianWhiteSpruce&Alder	F231XY196AK	1.1p (HCPCP)	Picea glauca	535
10	RiparianWhiteSpruce&Alder	F231XY196AK	1.2 (2AL)	Picea glauca	535
10	RiparianWhiteSpruce&Alder	F231XY197AK	1.1 (HCPC)	Picea glauca-Populus balsamifera/Alnus incana-Rosa acicularis/Equisetum arvense-Geocaulon lividum	569
11	RiparianWhiteSpruceForest	F231XY131AK	1.1 (HCPC)	Picea glauca/Rosa acicularis/Lupinus arcticus	256
11	RiparianWhiteSpruceForest	F231XY131AK	1.2 (2AL)	Picea glauca/Rosa acicularis/Lupinus arcticus	256
11	RiparianWhiteSpruceForest	F231XY196AK	1.1 (HCPC)	Picea glauca	535
21	WetHerb&Moss	R231XY137AK	1.2 (2PL)	Boreal Scrub Peat Floodplain	706

Table C2 (continued). USDA-NRCS ecosites of the land cover types. Ecosites are described in Parry (2013); page numbers are indicated in this table.

Cover Type Number	Cover Type Name	Ecosite	Phase	Ecosite Name	Page
21	WetHerb&Moss	R231XY137AK	1.3 (2PE)	Boreal Scrub Peat Floodplain	706
21	WetHerb&Moss	R231XY138AK	1.2 (2PL)	Boreal Scrub Loamy Depression	720
21	WetHerb&Moss	R231XY149AK	1.1 (HCPC)	Subalpine Graminoid Peat Swale	746
21	WetHerb&Moss	R231XY150AK	1.1 (HCPC)	Boreal Moss Peat Plain	753
21	WetHerb&Moss	R231XY150AK	1.2 (2KM)	Boreal Moss Peat Plain	753
21	WetHerb&Moss	R231XY150AK	1.3 (2KE)	Boreal Moss Peat Plain	753
21	WetHerb&Moss	R231XY158AK	1.1 (HCPC)	Boreal Scrub Peat Frozen Plains	777
21	WetHerb&Moss	R231XY158AK	1.3 (2KE)	Boreal Scrub Peat Frozen Plains	777
21	WetHerb&Moss	R231XY199AK	1.2 (2KL)	Boreal Graminoid Peat Terrace Depression	828
21	WetHerb&Moss	R231XY199AK	1.3 (2KE)	Boreal Graminoid Peat Terrace Depression	828
21	WetHerb&Moss	R232XY220AK	1.1 (2KE)	Boreal Moss Peat Depression	926
22	WetlandLowShrub	F231XY169AK	1.4 (2FE)	Picea mariana/Ledum palustre ssp. decumbens/Empetrum nigrum	361
22	WetlandLowShrub	F231XY178AK	1.4 (2FE)	Picea mariana/Vaccinium vitis-idaea-Rosa acicularis	389
22	WetlandLowShrub	R231XY128AK	1.1 (HCPC)	Boreal Tussock Peat Frozen Plains	674
22	WetlandLowShrub	R231XY128AK	1.2 (2FE)	Boreal Tussock Peat Frozen Plains	674
22	WetlandLowShrub	R231XY137AK	1.1 (HCPC)	Boreal Scrub Peat Floodplain	706
22	WetlandLowShrub	R231XY138AK	1.1 (HCPC)	Boreal Scrub Loamy Depression	720
22	WetlandLowShrub	R231XY199AK	1.1 (HCPC)	Boreal Graminoid Peat Terrace Depression	828
23	BlackSpruceWoodland	F231XY111AK	1.2 (2FL)	Picea mariana/Vaccinium vitis-idaea-Vaccinium uliginosum	184

Table C2 (continued). USDA-NRCS ecosites of the land cover types. Ecosites are described in Parry (2013); page numbers are indicated in this table.

Cover Type Number	Cover Type Name	Ecosite	Phase	Ecosite Name	Page
23	BlackSpruceWoodland	F231XY151AK	1.1p (HCPCP)	<i>Picea glauca</i> / <i>Alnus viridis</i> ssp. <i>fruticosa</i>	302
23	BlackSpruceWoodland	F231XY169AK	1.1 (HCPC)	<i>Picea mariana</i> / <i>Ledum palustre</i> ssp. <i>decumbens</i> / <i>Empetrum nigrum</i>	361
23	BlackSpruceWoodland	F231XY169AK	1.1p (HCPCP)	<i>Picea mariana</i> / <i>Ledum palustre</i> ssp. <i>decumbens</i> / <i>Empetrum nigrum</i>	361
23	BlackSpruceWoodland	F231XY169AK	1.2 (2FL)	<i>Picea mariana</i> / <i>Ledum palustre</i> ssp. <i>decumbens</i> / <i>Empetrum nigrum</i>	361
23	BlackSpruceWoodland	F232XY201AK	1.1 (HCPC)	<i>Picea mariana</i> / <i>Vaccinium uliginosum</i> - <i>Ledum groenlandicum</i>	841
23	BlackSpruceWoodland	F232XY203AK	1.1 (HCPC)	<i>Picea mariana</i> / <i>Salix pulchra</i> - <i>Alnus viridis</i> ssp. <i>fruticosa</i>	872
24	LichenLowShrub&Woodland	F231XY169AK	1.1p (HCPCP)	<i>Picea mariana</i> / <i>Ledum palustre</i> ssp. <i>decumbens</i> / <i>Empetrum nigrum</i>	361
24	LichenLowShrub&Woodland	F232XY201AK	1.1P (HCPC)	<i>Picea mariana</i> / <i>Vaccinium uliginosum</i> - <i>Ledum groenlandicum</i>	842
25	BlackSpruceForest	F231XY111AK	1.1 (HCPC)	<i>Picea mariana</i> / <i>Vaccinium vitis-idaea</i> - <i>Vaccinium uliginosum</i>	184
25	BlackSpruceForest	F231XY178AK	1.1 (HCPC)	<i>Picea mariana</i> / <i>Vaccinium vitis-idaea</i> - <i>Rosa acicularis</i>	389
25	BlackSpruceForest	F231XY192AK	1.1 (HCPC)	<i>Picea mariana</i> / <i>Alnus viridis</i> ssp. <i>fruticosa</i> / <i>Calamagrostis canadensis</i>	488

Table C2 (continued). USDA-NRCS ecosites of the land cover types. Ecosites are described in Parry (2013); page numbers are indicated in this table.

Cover Type Number	Cover Type Name	Ecosite	Phase	Ecosite Name	Page
25	BlackSpruceForest	F232XY201AK	1.2 (2FL)	Picea mariana/Vaccinium uliginosum-Ledum groenlandicum	841
25	BlackSpruceForest	F232XY227AK	1.1 (HCPC)	Picea mariana/Alnus viridis ssp. fruticosa-Ledum groenlandicum	912
31	TallShrubSeral	F231XY162AK	1.4 (2FE)	Picea mariana-Betula neoalaskana/Vaccinium uliginosum/Cladonia	322
31	TallShrubSeral	F231XY192AK	1.3 (2FE)	Picea mariana/Alnus viridis ssp. fruticosa/Calamagrostis canadensis	488
31	TallShrubSeral	F231XY193AK	1.3 (2FE)	Picea mariana/Salix-Ledum groenlandicum	505
31	TallShrubSeral	F231XY197AK	1.2 (2FL)	Picea glauca-Populus balsamifera/Alnus incana-Rosa acicularis/Equisetum arvense-Geocaulon lividum	569
31	TallShrubSeral	F232XY211AK	1.4 (2FE)	Picea glauca/Shepherdia canadensis-Rosa acicularis	899
31	TallShrubSeral	R231XY195AK	1.1 (HCPC)	Boreal Scrub Gravelly Drainages	798
31	TallShrubSeral	R231XY195AK	1.1 (HCPC)	Boreal Scrub Gravelly Drainages	521
31	TallShrubSeral	R231XY195AK	1.2 (2FL)	Boreal Scrub Gravelly Drainages	798
31	TallShrubSeral	R231XY195AK	1.2 (2FL)	Boreal Scrub Gravelly Drainages	521
32	DeciduousForestShort	F231XY117AK	1.3 (2FM)	Picea glauca/Alnus-Rosa acicularis	205
32	DeciduousForestShort	F231XY178AK	1.3 (2FM)	Picea mariana/Vaccinium vitis-idaea-Rosa acicularis	389
32	DeciduousForestShort	F231XY182AK	1.3 (2FM)	Picea glauca-Betula neoalaskana/Alnus viridis ssp. fruticosa-Rosa acicularis	435

Table C2 (continued). USDA-NRCS ecosites of the land cover types. Ecosites are described in Parry (2013); page numbers are indicated in this table.

Cover Type Number	Cover Type Name	Ecosite	Phase	Ecosite Name	Page
32	DeciduousForestShort	F232XY211AK	1.3 (2FM)	Picea glauca/Shepherdia canadensis-Rosa acicularis	899
33	DeciduousOpenForest&Woodland	F231XY110AK	1.3 (2FM)	Picea glauca-Populus tremuloides/Shepherdia canadensis-Rosa acicularis/Mertensia paniculata-Geocaulon lividum	160
34	DeciduousForest	F231XY117AK	1.3 (2FM)	Picea glauca/Alnus-Rosa acicularis	205
34	DeciduousForest	F231XY182AK	1.3 (2FM)	Picea glauca-Betula neoalaskana/Alnus viridis ssp. fruticosa-Rosa acicularis	435
34	DeciduousForest	F231XY192AK	1.2 (2FL)	Picea mariana/Alnus viridis ssp. fruticosa/Calamagrostis canadensis	488
35	MixedForestShort	F231XY111AK	1.3 (2FM)	Picea mariana/Vaccinium vitis-idaea-Vaccinium uliginosum	184
35	MixedForestShort	F231XY117AK	1.2 (2FL)	Picea glauca/Alnus-Rosa acicularis	205
35	MixedForestShort	F231XY162AK	1.2 (2FL)	Picea mariana-Betula neoalaskana/Vaccinium uliginosum/Cladonia	322
35	MixedForestShort	F231XY162AK	1.3 (2FM)	Picea mariana-Betula neoalaskana/Vaccinium uliginosum/Cladonia	322
35	MixedForestShort	F231XY169AK	1.3 (2FM)	Picea mariana/Ledum palustre ssp. decumbens/Empetrum nigrum	361
35	MixedForestShort	F231XY178AK	1.2 (2FL)	Picea mariana/Vaccinium vitis-idaea-Rosa acicularis	389
35	MixedForestShort	F231XY193AK	1.2 (2FL)	Picea mariana/Salix-Ledum groenlandicum	505

Table C2 (continued). USDA-NRCS ecosites of the land cover types. Ecosites are described in Parry (2013); page numbers are indicated in this table.

Cover Type Number	Cover Type Name	Ecosite	Phase	Ecosite Name	Page
35	MixedForestShort	F232XY203AK	1.2 (2FL)	<i>Picea mariana</i> / <i>Salix pulchra</i> - <i>Alnus viridis</i> ssp. <i>fruticosa</i>	872
35	MixedForestShort	F232XY210AK	1.3 (2FM)	<i>Picea glauca</i> - <i>Betula papyrifera</i> / <i>Alnus viridis</i> ssp. <i>fruticosa</i>	885
35	MixedForestShort	F232XY227AK	1.3 (2FM)	<i>Picea mariana</i> / <i>Alnus viridis</i> ssp. <i>fruticosa</i> - <i>Ledum groenlandicum</i>	912
36	MixedOpenForest&Woodland	F231XY110AK	1.1 (HCPC)	<i>Picea glauca</i> - <i>Populus tremuloides</i> / <i>Shepherdia canadensis</i> - <i>Rosa acicularis</i> / <i>Mertensia paniculata</i> - <i>Geocaulon lividum</i>	160
36	MixedOpenForest&Woodland	F231XY110AK	1.2 (2FL)	<i>Picea glauca</i> - <i>Populus tremuloides</i> / <i>Shepherdia canadensis</i> - <i>Rosa acicularis</i> / <i>Mertensia paniculata</i> - <i>Geocaulon lividum</i>	160
37	MixedForest	F231XY117AK	1.2 (2FL)	<i>Picea glauca</i> / <i>Alnus-Rosa acicularis</i>	205
37	MixedForest	F231XY131AK	1.1p (HCPCP)	<i>Picea glauca</i> / <i>Rosa acicularis</i> / <i>Lupinus arcticus</i>	256
37	MixedForest	F231XY182AK	1.2 (2FL)	<i>Picea glauca</i> - <i>Betula neoalaskana</i> / <i>Alnus viridis</i> ssp. <i>fruticosa</i> - <i>Rosa acicularis</i>	435
37	MixedForest	F231XY193AK	1.1 (HCPC)	<i>Picea mariana</i> / <i>Salix-Ledum groenlandicum</i>	505
37	MixedForest	F231XY196AK	1.2p (2FL)	<i>Picea glauca</i>	535
37	MixedForest	F232XY201AK	1.3 (2FM)	<i>Picea mariana</i> / <i>Vaccinium uliginosum</i> - <i>Ledum groenlandicum</i>	841
37	MixedForest	F232XY210AK	1.1 (HCPC)	<i>Picea glauca</i> - <i>Betula papyrifera</i> / <i>Alnus viridis</i> ssp. <i>fruticosa</i>	885

Table C2 (continued). USDA-NRCS ecosites of the land cover types. Ecosites are described in Parry (2013); page numbers are indicated in this table.

Cover Type Number	Cover Type Name	Ecosite	Phase	Ecosite Name	Page
37	MixedForest	F232XY211AK	1.2 (2FL)	Picea glauca/Shepherdia canadensis-Rosa acicularis	899
38	UplandSpruceForest	F231XY117AK	1.1 (HCPC)	Picea glauca/Alnus-Rosa acicularis	205
38	UplandSpruceForest	F231XY182AK	1.1 (HCPC)	Picea glauca-Betula neoalaskana/Alnus viridis ssp. fruticosa-Rosa acicularis	435
38	UplandSpruceForest	F232XY211AK	1.1 (HCPC)	Picea glauca/Shepherdia canadensis-Rosa acicularis	899
40	BluffBarrens	R231XY120AK	1.1 (HCPC)	Boreal Lichen Rock Outcrops Slopes	655
41	DryHerbaceous	R231XY109AK	1.2 (2FE)	Boreal Scrub Gravelly Slopes Dry	599
42	DryLowShrub	F231XY110AK	1.4 (2FE)	Picea glauca-Populus tremuloides/Shepherdia canadensis-Rosa acicularis/Mertensia paniculata-Geocaulon lividum	160
42	DryLowShrub	R231XY109AK	1.1 (HCPC)	Boreal Scrub Gravelly Slopes Dry	599
42	DryLowShrub	R231XY109AK	1.2 (2FE)	Boreal Scrub Gravelly Slopes Dry	599
50	Burned2021-2022	—	—	—	—
51	LowShrub&HerbBurned2015-2020	F231XY111AK	1.4 (2FE)	Picea mariana/Vaccinium vitis-idaea-Vaccinium uliginosum	184
51	LowShrub&HerbBurned2015-2020	F231XY117AK	1.4 (2FE)	Picea glauca/Alnus-Rosa acicularis	205
52	UplandLowWillow	F231XY117AK	1.4 (2FE)	Picea glauca/Alnus-Rosa acicularis	205
52	UplandLowWillow	F231XY162AK	1.4 (2FE)	Picea mariana-Betula neoalaskana/Vaccinium uliginosum/Cladonia	322

Table C2 (continued). USDA-NRCS ecosites of the land cover types. Ecosites are described in Parry (2013); page numbers are indicated in this table.

Cover Type Number	Cover Type Name	Ecosite	Phase	Ecosite Name	Page
52	UplandLowWillow	F231XY182AK	1.4 (2FE)	Picea glauca-Betula neoalaskana/Alnus viridis ssp. fruticosa-Rosa acicularis	435
52	UplandLowWillow	F231XY184AK	1.3 (2FE)	Picea glauca/Salix-Vaccinium uliginosum	458
52	UplandLowWillow	F231XY197AK	1.3 (2FE)	Picea glauca-Populus balsamifera/Alnus incana-Rosa acicularis/Equisetum arvense-Geocaulon lividum	569
53	UplandLowShrub	F231XY111AK	1.4 (2FE)	Picea mariana/Vaccinium vitis-idaea-Vaccinium uliginosum	184
53	UplandLowShrub	F231XY140AK	1.3 (2FE)	Picea glauca/Salix pulchra/Carex	285
53	UplandLowShrub	F231XY164AK	1.3 (2FE)	Picea glauca/Betula glandulosa-Empetrum nigrum	344
53	UplandLowShrub	F232XY201AK	1.4 (2FE)	Picea mariana/Vaccinium uliginosum-Ledum groenlandicum	841
54	SpruceWoodland&ShrubNorth	F231XY181AK	1.1 (HCPC)	Picea glauca/Rosa acicularis	409
54	SpruceWoodland&ShrubNorth	F231XY181AK	1.2 (2FL)	Picea glauca/Rosa acicularis	409
54	SpruceWoodland&ShrubNorth	F231XY181AK	1.3 (2FM)	Picea glauca/Rosa acicularis	409
54	SpruceWoodland&ShrubNorth	F231XY181AK	1.4 (2FE)	Picea glauca/Rosa acicularis	409
60	AcidicBarrens	R231XY127AK	1.1 (HCPC)	Alpine Lichen Rock Outcrops Slopes	668
61	AlkalineBarrens	R231XY127AK	1.1 (HCPC)	Alpine Lichen Rock Outcrops Slopes	668
62	AlpineDwarfShrub	R231XY101AK	1.1 (HCPC)	Alpine Dwarf Scrub Gravelly Hummock	585
62	AlpineDwarfShrub	R231XY105AK	1.1 (HCPC)	Alpine Dwarf Scrub Gravelly Slopes	592

Table C2 (continued). USDA-NRCS ecosites of the land cover types. Ecosites are described in Parry (2013); page numbers are indicated in this table.

Cover Type Number	Cover Type Name	Ecosite	Phase	Ecosite Name	Page
62	AlpineDwarfShrub	R231XY134AK	1.1 (HCPC)	Alpine Dwarf Scrub-Lichen Mosaic Gravelly Circles	696
62	AlpineDwarfShrub	R231XY134AK	1.1m (HPCPM)	Alpine Dwarf Scrub-Lichen Mosaic Gravelly Circles	696
63	AlpineSedge&DwarfShrub	R231XY113AK	1.1 (HCPC)	Alpine Dwarf Scrub-Graminoid Mosaic Loamy Mound	610
63	AlpineSedge&DwarfShrub	R231XY115AK	1.2 (2FE)	Alpine Lichen Loamy Frozen Polygon	631
63	AlpineSedge&DwarfShrub	R231XY116AK	1.1 (HCPC)	Alpine Dwarf Scrub-Graminoid Mosaic Organic Frozen Mound	641
63	AlpineSedge&DwarfShrub	R231XY116AK	1.2 (2FE)	Alpine Dwarf Scrub-Graminoid Mosaic Organic Frozen Mound	641
64	AlpineLowShrub	F231XY124AK	1.2 (2FL)	Picea mariana/Betula glandulosa	225
64	AlpineLowShrub	F231XY124AK	1.3 (2FM)	Picea mariana/Betula glandulosa	225
64	AlpineLowShrub	R231XY113AK	1.1d (HCPCD)	Alpine Dwarf Scrub-Graminoid Mosaic Loamy Mound	610
64	AlpineLowShrub	R231XY114AK	1.1 (HCPC)	Alpine Dwarf Scrub-Lichen Mosaic Peat Frozen Hummock	621
64	AlpineLowShrub	R231XY114AK	1.1m (HPCPM)	Alpine Dwarf Scrub-Lichen Mosaic Peat Frozen Hummock	621
64	AlpineLowShrub	R231XY116AK	1.1d (HCPCD)	Alpine Dwarf Scrub-Graminoid Mosaic Organic Frozen Mound	641
64	AlpineLowShrub	R231XY129AK	1.2 (2FL)	Subalpine Scrub Loamy Frozen Circles	681
64	AlpineLowShrub	R231XY129AK	1.3 (2FE)	Subalpine Scrub Loamy Frozen Circles	681
64	AlpineLowShrub	R231XY139AK	1.1 (HCPC)	Subalpine Scrub Loamy Slopes	731
64	AlpineLowShrub	R231XY148AK	1.1 (HCPC)	Subalpine Scrub Loamy Hummock	738

Table C2 (continued). USDA-NRCS ecosites of the land cover types. Ecosites are described in Parry (2013); page numbers are indicated in this table.

Cover Type Number	Cover Type Name	Ecosite	Phase	Ecosite Name	Page
64	AlpineLowShrub	R231XY152AK	1.1 (HCPC)	Subalpine Scrub Loamy Drainages	764
64	AlpineLowShrub	R231XY185AK	1.1 (HCPC)	Subalpine Scrub Loamy Frozen Hummock	787
64	AlpineLowShrub	R231XY185AK	1.2 (2FE)	Subalpine Scrub Loamy Frozen Hummock	787
65	SubalpineTallShrub	R231XY195AK	1.1 (HCPC)	Boreal Scrub Gravelly Drainages	798
65	SubalpineTallShrub	R231XY195AK	1.2 (2FL)	Boreal Scrub Gravelly Drainages	798
66	TussockTundra	R231XY128AK	1.1 (HCPC)	Boreal Tussock Peat Frozen Plains	674
66	TussockTundra	R231XY128AK	1.2 (2FE)	Boreal Tussock Peat Frozen Plains	674
67	LichenTundra	R231XY115AK	1.1 (HCPC)	Alpine Lichen Loamy Frozen Polygon	631
68	SubalpineSpruceWoodland	F231XY124AK	1.1 (HCPC)	Picea mariana/Betula glandulosa	225
68	SubalpineSpruceWoodland	F231XY140AK	1.1 (HCPC)	Picea glauca/Salix pulchra/Carex	285
68	SubalpineSpruceWoodland	F231XY140AK	1.2 (2FL)	Picea glauca/Salix pulchra/Carex	285
68	SubalpineSpruceWoodland	F231XY184AK	1.1 (HCPC)	Picea glauca/Salix-Vaccinium uliginosum	458
68	SubalpineSpruceWoodland	F231XY184AK	1.2 (2FL)	Picea glauca/Salix-Vaccinium uliginosum	458
68	SubalpineSpruceWoodland	R231XY129AK	1.1 (HCPC)	Subalpine Scrub Loamy Frozen Circles	681
69	SubalpineSpruceLichenWoodland	F231XY164AK	1.1 (HCPC)	Picea glauca/Betula glandulosa-Empetrum nigrum	344
69	SubalpineSpruceLichenWoodland	F231XY164AK	1.2 (2FL)	Picea glauca/Betula glandulosa-Empetrum nigrum	344

Table C3. US National Vegetation Classification groups of the land cover classes (USNVC 2023).

Cover Type Number	Cover Type Name	USNVC Group Name
1	Water	–
2	AquaticVegetation	G769 North American Boreal Freshwater Aquatic Vegetation Group
3	RiparianBarrens	G616 Arctic Gravel Floodplain Vegetation Group
4	MineTailingBarrens	–
5	RiparianLowShrub&Herb	–
6	RiparianTallShrub	–
7	RiparianYoungPoplarForest	G548 Alaskan-Yukon Boreal Flooded & Rich Swamp Group
8	RiparianPoplarForest	G548 Alaskan-Yukon Boreal Flooded & Rich Swamp Group
9	RiparianMixedForest	G548 Alaskan-Yukon Boreal Flooded & Rich Swamp Group
10	RiparianWhiteSpruce&Alder	G548 Alaskan-Yukon Boreal Flooded & Rich Swamp Group
11	RiparianWhiteSpruceForest	G548 Alaskan-Yukon Boreal Flooded & Rich Swamp Group
21	WetHerb&Moss	G528 Western Boreal Wet Meadow & Marsh Group
22	WetlandLowShrub	G360 Western North American Boreal Bog & Acidic Fen Group
23	BlackSpruceWoodland	G546 Alaskan-Yukon Boreal Black Spruce Wet Forest Group
24	LichenLowShrub&Woodland	G546 Alaskan-Yukon Boreal Black Spruce Wet Forest Group
25	BlackSpruceForest	G856 Central Alaskan Boreal Montane Woodland Group
31	TallShrubSeral	G357 Western Boreal Mesic Alder - Willow Shrubland Group
32	DeciduousForestShort	G579 Central Alaskan-Yukon Boreal Mesic Forest Group
33	DeciduousOpenForest&Woodland	G349 Alaskan Boreal Dry Aspen Forest Group
34	DeciduousForest	G579 Central Alaskan-Yukon Boreal Mesic Forest Group
35	MixedForestShort	G579 Central Alaskan-Yukon Boreal Mesic Forest Group
36	MixedOpenForest&Woodland	G349 Alaskan Boreal Dry Aspen Forest Group
37	MixedForest	G579 Central Alaskan-Yukon Boreal Mesic Forest Group
38	UplandSpruceForest	G579 Central Alaskan-Yukon Boreal Mesic Forest Group
40	BluffBarrens	G822 Western Boreal Cliff, Scree & Rock Vegetation Group
41	DryHerbaceous	G359 Western Boreal Dry Shrubland & Grassland Group
42	DryLowShrub	G359 Western Boreal Dry Shrubland & Grassland Group
50	Burned2021-2022	–
51	LowShrub&HerbBurned2015-2020	G356 Western Boreal Mesic Birch - Willow Low Shrubland Group
52	UplandLowWillow	G356 Western Boreal Mesic Birch - Willow Low Shrubland Group
53	UplandLowShrub	G356 Western Boreal Mesic Birch - Willow Low Shrubland Group

Table C3 (continued). US National Vegetation Classification groups of the land cover classes (USNVC 2023).

Cover Type Number	Cover Type Name	USNVC Group Name
54	SpruceWoodland&ShrubNorth	G356 Western Boreal Mesic Birch - Willow Low Shrubland Group
60	AcidicBarrens	G868 Arctic Lichen Barrens Group
61	AlkalineBarrens	G869 Arctic Open Scree, Rock & Cliff Barrens Group
62	AlpineDwarfShrub	G896 Arctic Dwarf-shrub Tundra Group
63	AlpineSedge&DwarfShrub	G898 Arctic Herbaceous Tundra Group
64	AlpineLowShrub	G356 Western Boreal Mesic Birch - Willow Low Shrubland Group
65	SubalpineTallShrub	G848 Alaskan-Yukon Boreal Montane Alder - Willow Shrubland Group
66	TussockTundra	G898 Arctic Herbaceous Tundra Group
67	LichenTundra	G898 Arctic Herbaceous Tundra Group
68	SubalpineSpruceWoodland	G859 Alaska-Yukon Northern Boreal Mesic Woodland Group
69	SubalpineSpruceLichenWoodland	G859 Alaska-Yukon Northern Boreal Mesic Woodland Group

Table C4. The Alaska Vegetation Classification (Vioreck et al. 1992) of the land cover classes.

Cover Type Number	Cover Type Name	Level III Symbol	Level III Name
1	Water	–	–
2	AquaticVegetation	IIID1	Freshwater aquatic herbaceous
3	RiparianBarrens	–	–
4	MineTailingBarrens	–	–
5	RiparianLowShrub&Herb	IIC1	Closed low scrub
5	RiparianLowShrub&Herb	IIC2	Open low scrub
5	RiparianLowShrub&Herb	IIIA2	Mesic graminoid herbaceous
6	RiparianTallShrub	IIB1	Closed tall scrub
6	RiparianTallShrub	IIB2	Open tall scrub
7	RiparianYoungPoplarForest	IB1	Closed broadleaf forest
7	RiparianYoungPoplarForest	IB2	Open broadleaf forest
8	RiparianPoplarForest	IB1	Closed broadleaf forest
8	RiparianPoplarForest	IB2	Open broadleaf forest
9	RiparianMixedForest	IC1	Closed mixed forest
9	RiparianMixedForest	IC2	Open mixed forest
10	RiparianWhiteSpruce&Alder	IA2	Open needleleaf (conifer) forest
11	RiparianWhiteSpruceForest	IA2	Open needleleaf (conifer) forest
21	WetHerb&Moss	IIIA3	Wet graminoid herbaceous (emergent)
21	WetHerb&Moss	IIIC1	Mosses
22	WetlandLowShrub	IIC2	Open low scrub
23	BlackSpruceWoodland	IA3	Needleleaf (conifer) woodland
23	BlackSpruceWoodland	IIA3	Dwarf tree scrub woodland
24	LichenLowShrub&Woodland	IA3	Needleleaf (conifer) woodland
24	LichenLowShrub&Woodland	IIA3	Dwarf tree scrub woodland
25	BlackSpruceForest	IA1	Closed needleleaf (conifer) forest
25	BlackSpruceForest	IA2	Open needleleaf (conifer) forest
31	TallShrubSeral	IIB1	Closed tall scrub
31	TallShrubSeral	IIB2	Open tall scrub
32	DeciduousForestShort	IB1	Closed broadleaf forest
32	DeciduousForestShort	IB2	Open broadleaf forest
33	DeciduousOpenForest&Woodland	IB2	Open broadleaf forest
33	DeciduousOpenForest&Woodland	IB3	Broadleaf woodland
34	DeciduousForest	IB1	Closed broadleaf forest
35	MixedForestShort	IC2	Open mixed forest
36	MixedOpenForest&Woodland	IC2	Open mixed forest
36	MixedOpenForest&Woodland	IC3	Mixed woodland

Table C4 (continued). The Alaska Vegetation Classification (Viereck et al. 1992) of the land cover classes.

Cover Type Number	Cover Type Name	Level III Symbol	Level III Name
37	MixedForest	IC1	Closed mixed forest
37	MixedForest	IC2	Open mixed forest
38	UplandSpruceForest	IA2	Open needleleaf (conifer) forest
40	BluffBarrens	–	–
41	DryHerbaceous	IIIA1	Dry graminoid herbaceous
42	DryLowShrub	IIC2	Open low scrub
50	Burned2021-2022	–	–
51	LowShrub&HerbBurned2015-2020	IIC2	Open low scrub
51	LowShrub&HerbBurned2015-2020	IIIA2	Mesic graminoid herbaceous
51	LowShrub&HerbBurned2015-2020	IIIB2	Mesic forb herbaceous
52	UplandLowWillow	IIC1	Closed low scrub
52	UplandLowWillow	IIC2	Open low scrub
53	UplandLowShrub	IIC1	Closed low scrub
53	UplandLowShrub	IIC2	Open low scrub
54	SpruceWoodland&ShrubNorth	IA3	Needleleaf (conifer) woodland
54	SpruceWoodland&ShrubNorth	IIC2	Open low scrub
60	AcidicBarrens	IIIC2	Lichens
61	AlkalineBarrens	–	–
62	AlpineDwarfShrub	IID1	Dryas dwarf scrub
62	AlpineDwarfShrub	IID2	Ericaceous dwarf scrub
62	AlpineDwarfShrub	IID3	Willow dwarf scrub
63	AlpineSedge&DwarfShrub	IID1	Dryas dwarf scrub
63	AlpineSedge&DwarfShrub	IID2	Ericaceous dwarf scrub
63	AlpineSedge&DwarfShrub	IIIA2	Mesic graminoid herbaceous
64	AlpineLowShrub	IIC1	Closed low scrub
64	AlpineLowShrub	IIC2	Open low scrub
65	SubalpineTallShrub	IIB1	Closed tall scrub
65	SubalpineTallShrub	IIB2	Open tall scrub
66	TussockTundra	IIIA2	Mesic graminoid herbaceous
67	LichenTundra	IIIA2	Mesic graminoid herbaceous
68	SubalpineSpruceWoodland	IA3	Needleleaf (conifer) woodland
69	SubalpineSpruceLichenWoodland	IA2	Open needleleaf (conifer) forest
69	SubalpineSpruceLichenWoodland	IA3	Needleleaf (conifer) woodland

Table C5. Equivalent land cover types in the present study and the previous YUCH land cover map (Ducks Unlimited 2002).

Cover Type Number	Cover Type Name	DU symbol	DU name
1	Water	70	Clear Water
1	Water	71	Turbid Water
2	AquaticVegetation	60	Aquatic Bed
3	RiparianBarrens	80	Sparsely Vegetated
4	MineTailingBarrens	80	Sparsely Vegetated
5	RiparianLowShrub&Herb	21	Low Shrub
6	RiparianTallShrub	20	Tall Shrub
7	RiparianYoungPoplarForest	10	Closed Deciduous Forest
7	RiparianYoungPoplarForest	13	Open Deciduous Forest
8	RiparianPoplarForest	10	Closed Deciduous Forest
8	RiparianPoplarForest	13	Open Deciduous Forest
9	RiparianMixedForest	16	Closed Mixed Needleleaf / Deciduous Forest
9	RiparianMixedForest	17	Open Mixed Needleleaf / Deciduous Forest
10	RiparianWhiteSpruce&Alder	2	Open Needleleaf Forest
11	RiparianWhiteSpruceForest	2	Open Needleleaf Forest
21	WetHerb&Moss	32	Wet graminoid
21	WetHerb&Moss	34	Wet Sedge
22	WetlandLowShrub	23	Low Shrub Tussock
23	BlackSpruceWoodland	4	Woodland Needleleaf Forest
23	BlackSpruceWoodland	6	Woodland Needleleaf Moss Forest
24	LichenLowShrub&Woodland	5	Woodland Needleleaf Lichen Forest
24	LichenLowShrub&Woodland	22	Low Shrub Lichen
25	BlackSpruceForest	1	Closed Needleleaf Forest
25	BlackSpruceForest	2	Open Needleleaf Forest
31	TallShrubSeral	20	Tall Shrub
32	DeciduousForestShort	10	Closed Deciduous Forest
32	DeciduousForestShort	13	Open Deciduous Forest
33	DeciduousOpenForest&Woodland	13	Open Deciduous Forest
34	DeciduousForest	10	Closed Deciduous Forest
35	MixedForestShort	17	Open Mixed Needleleaf / Deciduous Forest
36	MixedOpenForest&Woodland	17	Open Mixed Needleleaf / Deciduous Forest
37	MixedForest	16	Closed Mixed Needleleaf / Deciduous Forest
37	MixedForest	17	Open Mixed Needleleaf / Deciduous Forest
38	UplandSpruceForest	2	Open Needleleaf Forest
40	BluffBarrens	81	Rock/Gravel

Table C5 (continued). Equivalent land cover types in the present study and the previous YUCH land cover map (Ducks Unlimited 2002).

Cover Type Number	Cover Type Name	DU symbol	DU name
41	DryHerbaceous	80	Sparsely Vegetated
42	DryLowShrub	80	Sparsely Vegetated
50	Burned2021-2022	96	Fire (Burned)
51	LowShrub&HerbBurned2015-2020	21	Low Shrub
52	UplandLowWillow	21	Low Shrub
53	UplandLowShrub	21	Low Shrub
54	SpruceWoodland&ShrubNorth	4	Woodland Needleleaf Forest
54	SpruceWoodland&ShrubNorth	6	Woodland Needleleaf Moss Forest
54	SpruceWoodland&ShrubNorth	21	Low Shrub
54	SpruceWoodland&ShrubNorth	94	Terrain Shadow
60	AcidicBarrens	81	Rock/Gravel
61	AlkalineBarrens	81	Rock/Gravel
62	AlpineDwarfShrub	24	Dwarf Shrub
63	AlpineSedge&DwarfShrub	40	Dry Herbaceous
64	AlpineLowShrub	21	Low Shrub
65	SubalpineTallShrub	20	Tall Shrub
66	TussockTundra	50	Tussock Tundra
67	LichenTundra	51	Tussock Tundra - Lichen
68	SubalpineSpruceWoodland	4	Woodland Needleleaf Forest
68	SubalpineSpruceWoodland	6	Woodland Needleleaf Moss Forest
69	SubalpineSpruceLichenWoodland	3	Open Needleleaf Lichen Forest
69	SubalpineSpruceLichenWoodland	5	Woodland Needleleaf Lichen Forest

Table C6. Simplified legend options.

Map		Level II ^A			Level I ^B			Ecological ^C	
Value	Class Name	Value	Symbol	Name	Value	Symbol	Name	Value	Name
1	Water	11	NA	Water	6	NA	Water	13	Water
2	AquaticVegetation	8	IIID	Aquatic (nonemergent) herbaceous	3	III	Herbaceous	13	Water
3	RiparianBarrens	9	NA	Barrens	4	NA	Barrens	7	Riparian Barrens
4	MineTailingBarrens	9	NA	Barrens	4	NA	Barrens	7	Riparian Barrens
5	RiparianLowShrub&Herb	5	IIC	Low scrub	2	II	Scrub	9	Riparian Shrub & Herb
6	RiparianTallShrub	4	IIB	Tall scrub	2	II	Scrub	9	Riparian Shrub & Herb
7	RiparianYoungPoplarForest	2	IB	Broadleaf forest	1	I	Forest	8	Riparian Forest
8	RiparianPoplarForest	2	IB	Broadleaf forest	1	I	Forest	8	Riparian Forest
9	RiparianMixedForest	3	IC	Mixed forest	1	I	Forest	8	Riparian Forest
10	RiparianWhiteSpruce&Alder	1	IA	Needleleaf (conifer) forest	1	I	Forest	8	Riparian Forest
11	RiparianWhiteSpruceForest	1	IA	Needleleaf (conifer) forest	1	I	Forest	8	Riparian Forest
21	WetHerb&Moss	7	IIIA	Graminoid herbaceous	3	III	Herbaceous	6	Lowland Spruce Forest & Shrub
22	WetlandLowShrub	5	IIC	Low scrub	2	II	Scrub	6	Lowland Spruce Forest & Shrub
23	BlackSpruceWoodland	1	IA	Needleleaf (conifer) forest	1	I	Forest	6	Lowland Spruce Forest & Shrub
24	LichenLowShrub&Woodland	1	IA	Needleleaf (conifer) forest	1	I	Forest	6	Lowland Spruce Forest & Shrub
25	BlackSpruceForest	1	IA	Needleleaf (conifer) forest	1	I	Forest	6	Lowland Spruce Forest & Shrub

^A based on the Alaska Vegetation Classification level II (Viereck et al. 1992)

^B based on the Alaska Vegetation Classification level I (Viereck et al. 1992)

^C Types judged by the author to be ecologically similar based on vegetation, soil, and landscape setting.

Table C6 (continued). Simplified legend options.

Map		Level II ^A			Level I ^B			Ecological ^C	
Value	Class Name	Value	Symbol	Name	Value	Symbol	Name	Value	Name
31	TallShrubSeral	4	IIB	Tall scrub	2	II	Scrub	10	Seral Shrub
32	DeciduousForestShort	2	IB	Broadleaf forest	1	I	Forest	5	Deciduous & Mixed Forest
33	DeciduousOpenForest &Woodland	2	IB	Broadleaf forest	1	I	Forest	5	Deciduous & Mixed Forest
34	DeciduousForest	2	IB	Broadleaf forest	1	I	Forest	5	Deciduous & Mixed Forest
35	MixedForestShort	3	IC	Mixed forest	1	I	Forest	5	Deciduous & Mixed Forest
36	MixedOpenForest &Woodland	3	IC	Mixed forest	1	I	Forest	5	Deciduous & Mixed Forest
37	MixedForest	3	IC	Mixed forest	1	I	Forest	5	Deciduous & Mixed Forest
38	UplandSpruceForest	1	IA	Needleleaf (conifer) forest	1	I	Forest	12	Upland Spruce Forest
40	BluffBarrens	9	NA	Barrens	4	NA	Barrens	3	Bluff Barrens Herb & Shrub
41	DryHerbaceous	7	IIIA	Graminoid herbaceous	3	III	Herbaceous	3	Bluff Barrens Herb & Shrub
42	DryLowShrub	5	IIC	Low scrub	2	II	Scrub	3	Bluff Barrens Herb & Shrub
50	Burned2021-2022	10	NA	Burned2021-2022	5	NA	Burned2021- 2022	4	Burned2021-2022
51	LowShrub&Herb Burned2015-2020	5	IIC	Low scrub	2	II	Scrub	10	Seral Shrub
52	UplandLowWillow	5	IIC	Low scrub	2	II	Scrub	10	Seral Shrub
53	UplandLowShrub	5	IIC	Low scrub	2	II	Scrub	10	Seral Shrub
54	SpruceWoodland &ShrubNorth	1	IA	Needleleaf (conifer) forest	1	I	Forest	12	Upland Spruce Forest
60	AcidicBarrens	9	NA	Barrens	4	NA	Barrens	1	Alpine Barrens
61	AlkalineBarrens	9	NA	Barrens	4	NA	Barrens	1	Alpine Barrens

^A based on the Alaska Vegetation Classification level II (Vioreck et al. 1992)

^B based on the Alaska Vegetation Classification level I (Vioreck et al. 1992)

^C Types judged by the author to be ecologically similar based on vegetation, soil, and landscape setting.

Table C6 (continued). Simplified legend options.

Map		Level II ^A			Level I ^B			Ecological ^C	
Value	Class Name	Value	Symbol	Name	Value	Symbol	Name	Value	Name
62	AlpineDwarfShrub	6	IID	Dwarf scrub	2	II	Scrub	2	Alpine Tundra & Shrub
63	AlpineSedge&DwarfShrub	7	IIIA	Graminoid herbaceous	3	III	Herbaceous	2	Alpine Tundra & Shrub
64	AlpineLowShrub	5	IIC	Low scrub	2	II	Scrub	2	Alpine Tundra & Shrub
65	SubalpineTallShrub	4	IIB	Tall scrub	2	II	Scrub	2	Alpine Tundra & Shrub
66	TussockTundra	7	IIIA	Graminoid herbaceous	3	III	Herbaceous	2	Alpine Tundra & Shrub
67	LichenTundra	7	IIIA	Graminoid herbaceous	3	III	Herbaceous	2	Alpine Tundra & Shrub
68	SubalpineSpruceWoodland	1	IA	Needleleaf (conifer) forest	1	I	Forest	11	Subalpine Spruce Woodland
69	SubalpineSpruceLichen Woodland	1	IA	Needleleaf (conifer) forest	1	I	Forest	11	Subalpine Spruce Woodland

^A based on the Alaska Vegetation Classification level II (Viereck et al. 1992)

^B based on the Alaska Vegetation Classification level I (Viereck et al. 1992)

^C Types judged by the author to be ecologically similar based on vegetation, soil, and landscape setting.

Appendix D: Random Forest Classification Results

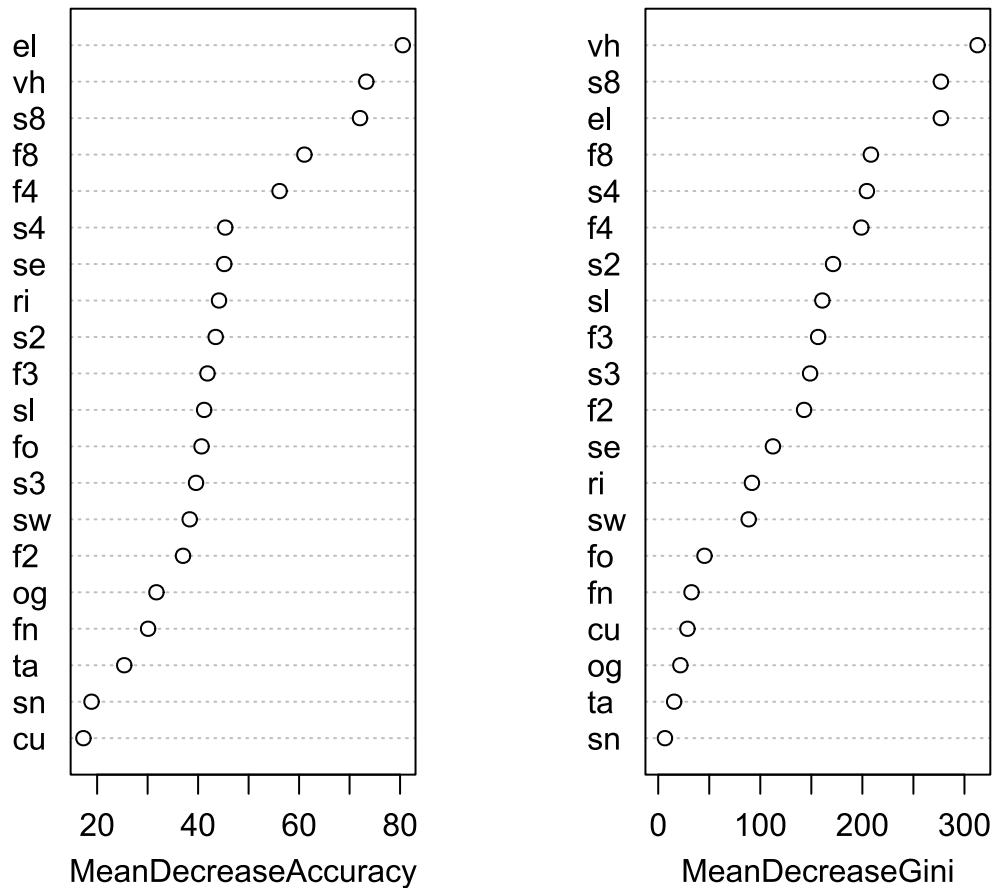


Figure D1. Random Forest Variable Importance Plot. Two importance indexes are provided, see the documentation for the R package “randomForest” (Liaw and Wiener 2002) for details. The DEM-based variables are: cu curvature, el elevation, se southeastness, sl slope, sw southwestness, vh vegetation height. The spectral variables are: f2, f3, f4, f8, s2, s3, s4, s8 fall (f) and summer (s) bands 2 blue, 3 green, 4 red, 8 near-infrared. The regional mask variables are: fn Fires 2021-2022, fo Fires 2015-2020, og Ogilvie Mountains, ri riparian, sn Snowy Domes Subsection, ta mine tailings.

Table D1. Random Forest classification matrix—part one. Rows are map classes and columns original assigned classes, for class definitions see Table 3. “prod” and “user” are producer’s and user’s accuracies.

Map	Train																							
	1	2	3	4	5	6	7	8	9	10	11	21	22	23	24	25	31	32	33	34	35	36	37	38
1	128	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	16	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	93	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	1	0	0	67	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	52	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	37	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	2	46	9	2	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	6	15	0	0	0	0	0	1	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	8	1	84	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	46	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	3	158	20	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	10	87	4	7	1	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	3	92	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	93	0	0	0	0	2	1	0	5
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	63	0	3	0	0	1	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	99	2	0	4	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	32	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	51	0	0	1	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	7	0	0	73	2	0	1
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	1	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	48	1
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	6	0	1	64

Table D1 (continued). Random Forest classification matrix—part one. Rows are map classes and columns original assigned classes, for class definitions see Table 3. “prod” and “user” are producer’s and user’s accuracies.

Map	Train																							
	1	2	3	4	5	6	7	8	9	10	11	21	22	23	24	25	31	32	33	34	35	36	37	38
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	2	8	2	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	4	0	0	1	0	0	2
60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	0	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	5
69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
prod	99	84	100	97	96	100	100	95	74	60	98	90	90	70	94	86	89	88	86	98	85	77	94	82

Table D2. Random Forest classification matrix—part two. Rows are map classes and columns original assigned classes, for class definitions see Table 3. “prod” and “user” are producer’s and user’s accuracies.

Map	Train																		
	40	41	42	50	51	52	53	54	60	61	62	63	64	65	66	67	68	69	user
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	98
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	89
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	98
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
5	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	94
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	98
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	95
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	78
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	68
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90
21	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	98
22	0	0	0	0	0	1	3	0	0	0	0	0	2	0	4	0	0	0	83
23	0	0	0	0	0	0	5	1	0	0	0	0	0	0	0	0	0	1	75
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	97
25	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	86
31	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	91
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	93
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	89
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	96
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	85
36	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	92
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	92
38	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3	0	83

Table D2 (continued). Random Forest classification matrix—part two. Rows are map classes and columns original assigned classes, for class definitions see Table 3. “prod” and “user” are producer’s and user’s accuracies.

Map	Train																		
	40	41	42	50	51	52	53	54	60	61	62	63	64	65	66	67	68	69	user
40	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
41	0	24	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	96
42	0	1	23	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	85
50	0	0	0	67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
51	0	0	0	0	70	0	0	0	0	0	0	0	0	0	0	0	0	0	100
52	0	0	0	0	0	21	2	0	0	0	0	0	1	0	0	0	0	0	84
53	1	0	0	0	0	1	48	0	1	0	0	0	0	0	0	0	0	0	76
54	0	0	0	0	1	0	1	66	0	0	0	0	0	0	0	0	1	1	84
60	0	0	0	0	0	0	0	0	107	1	1	0	1	0	0	0	0	0	97
61	0	0	0	0	0	0	0	0	1	35	0	0	0	0	0	0	0	0	97
62	0	0	0	0	0	0	0	0	0	0	81	1	0	0	0	0	0	0	99
63	0	0	0	0	0	0	0	0	0	0	3	24	1	0	0	0	0	0	86
64	0	0	0	0	0	0	2	0	0	0	0	3	156	1	0	0	4	0	92
65	0	0	0	0	0	0	0	0	0	0	0	0	1	16	0	0	0	0	94
66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	47	0	0	0	94
67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	100
68	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0	0	73	0	86
69	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	69	95
prod	95	96	92	100	99	78	75	99	98	97	95	86	93	76	92	100	90	96	91

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 191/189982, August 2023

National Park Service
U.S. Department of the Interior



[Natural Resource Stewardship and Science](#)

1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

EXPERIENCE YOUR AMERICA™