Dene K’éh Kusān (DKK) Wetland Classification User’s Guide

March 2023

Prepared for Dena Kayeh Institute and Kaska Dena Council
by
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Dene K'éh Kusān Wetland Classification was produced by Ducks Unlimited Canada's National Boreal Program contractually with Kaska Dena Council. This document was prepared to describe the methodologies and results of the developed spatial dataset.

Notifications of errors or omissions should be directed to Ducks Unlimited Canada's National Boreal Program.

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Summary

Dene K’éh Kusān (DKK) which means, “always will be there” in Kaska, is a proposed Indigenous Protected and Conserved Area (IPCA) in northern British Columbia, which will protect their ancestral territory from biodiversity loss while creating economic opportunity for Kaska Dena and the surrounding communities. Ducks Unlimited Canada’s (DUC) National Boreal Program has partnered with the Dena Keyah Institute and Dane nan yḗ dāh Kaska Land Guardian Program to support their IPCA management plan, by providing wetland maps to complement their planning and decision-making processes. DUC’s wetland classifications use multi-source Earth Observation datasets, including optical, radar and topographic imagery, to create large-scale, detailed maps based on the five major classes of the Canadian Wetland Classification System (CWCS; open water, marsh, fen, bog, swamp) and then to DUC’s Enhanced Wetland Classification (EWC) system (~19 classes). We use various types of reference data (helicopter-based vegetation surveys and high-resolution photo-interpreted sites) to train and validate our machine learning models to understand the different wetland types and complexes across the landscape. The results of the detailed EWC product, which consisted of 18 classes (of which 9 were wetland classes), had an overall accuracy of 84%. At the more general Canadian Wetland Classification System detail, which included three major wetland classes (open water, fen, and swamp), the overall accuracy was 94%. The results are a set of reliable and easy-to-read collection of spatial information to support the on-going management of the Kaska region, a region we hope “always will be there.”

1.0 DKK Project Overview

The boreal forest of Canada consists of a vast mosaic of forests, lakes, rivers, and wetlands that cover more than 2.7 million km^2. Boreal wetlands represent a large percentage of the landscape and provide critical ecosystem services by helping mitigate the effects of floods and droughts, providing key habitat for flora and fauna, recycling nutrients, storing and sequestering carbon, and purifying large volumes of water. They also provide an excellent landscape for subsistence and recreational hunting and fishing for local communities. Advancing our understanding of these wetlands is critical due to the expansion of industrial development, climate change, and an increased need to manage wildlife populations, as well as for use in policy development and implementation.

DKK, which means "always will be there" in Kaska, is a proposed IPCA in Northern British Columbia, which will preserve the ancestral territory of the Kaska Dena from biodiversity loss and unsustainable development while creating economic opportunity for the Kaska Dena and the surrounding communities (Dene K'éh Kusān, 2023). DKK holds 9.6 million acres (3.9 million hectares) of remote landscape located in the Boreal Cordillera ecozone, rich in lush wetlands and diverse wildlife like caribou, moose, elk, mountain goat, and waterfowl. It also has deep cultural significance for Daylu Dena Council, Dease River First Nation, Kwadacha Nation, Liard First Nation, and Ross River Dena Council.

Advancing our understanding of this region's ecology, including its associated wetlands, is critical for supporting conservation and monitoring activities. DUC National Boreal Program has partnered with the Dena Keyah Institute and Dane nan yḗ dāh Kaska Land Guardian Program to support their IPCA management plan, by developing an EWC map to complement their planning and decision-making processes. This project is part of a long effort by DUC National Boreal Program to provide baseline wetland mapping across Canada's western boreal region. To date, DUC has mapped over 147 million hectares (363 million acres) throughout northwestern Canada (Figure 1).

This report describes the satellite-based EWC mapping of the DKK proposed IPCA. This project provides a comprehensive hierarchical wetland inventory (Appendix A) of a diverse and valuable region that will aid in its conservation, baseline monitoring, and planning. More specifically, the inventory will help serve the following two key objectives: 1) profiling the types and extent of boreal wetlands, serving as a long-term monitoring measure of the region; and 2) baseline support for analysis of habitat use and requirements of various species.

Figure 1. DUC's National Boreal Program mapping projects. DKK (Kaska) in Northern British Columbia.

2.0 Project Deliverables

The objective of this project was to develop a baseline wetland inventory of the DKK region, in support of Dena Keyah Institute and councils' endeavor to protect the biodiversity of the area and contribute to its cultural continuity.

This EWC product is comprised of a digital wetland map of the region and a comprehensive digital database of interpreted and field verified reference data that can be easily integrated into a geographic information system (GIS). GIS provides the ability to spatially relate the enhanced wetland data to wildlife, sociological, and other pertinent datasets. This allows managers to identify crucial areas for wildlife, perform habitat assessments, plot movement patterns for large ungulates, and generate risk assessments for proposed projects.

3.0 Funding

Funding for this work was provided by North America Wetland Conservation Act (NAWCA), Environment and Climate Change Canada (ECCC), and support through Dena Keyah Institute funding source.

4.0 Project Area

The DKK project area is located in northern British Columbia. The project area covers approximately 9.6 million acres (3.9 million hectares) which includes a 500 m buffer around IPCA boundary. The project area is located within the Boreal Cordillera ecozones, which cover four distinct ecoregions: Boreal Mountains and Plateaus, Liard Basin, Hyland Highland, Northern Canadian Rocky Mountains (Figure 2).

The boreal forest extends across the continent and includes the Boreal Cordillera ecozone, where it is characterized by large changes in elevation (Figure 2), temperature, and precipitation over relatively short distances (Smith et al., 2004). The climate ranges from sub-humid to semi-arid, with mean annual temperatures of 1.0 to 5.5 °C, and precipitation varies from less than 300 mm in rain shadow-effected valleys to 1000 mm in the interior ranges. Vegetation varies by elevation and aspect. Grasslands can be found on south-facing slopes, along with deciduous uplands, while typical boreal vegetation characterizes north-facing slopes. Common species found at lower elevations include white and black spruce, lodgepole pine, aspen, balsam poplar, birch, and subalpine fir; however, subalpine fir are less common in the DKK project area than in other parts of the ecozone. Higher elevations support areas of alpine tundra composed of sedges, mosses, and lichens. Permafrost is sporadic and isolated (Figure 2). The mountains and plateaus are dominant features separated by lowlands and valleys. Debris and deposits from glaciation cover the plateaus and valleys. On lower slopes and valley bottoms, soils are commonly rich in organic matter, covered in peat. Forest fires are frequent throughout the ecozone, resulting in a mosaic of forest stands in various stages of regeneration.

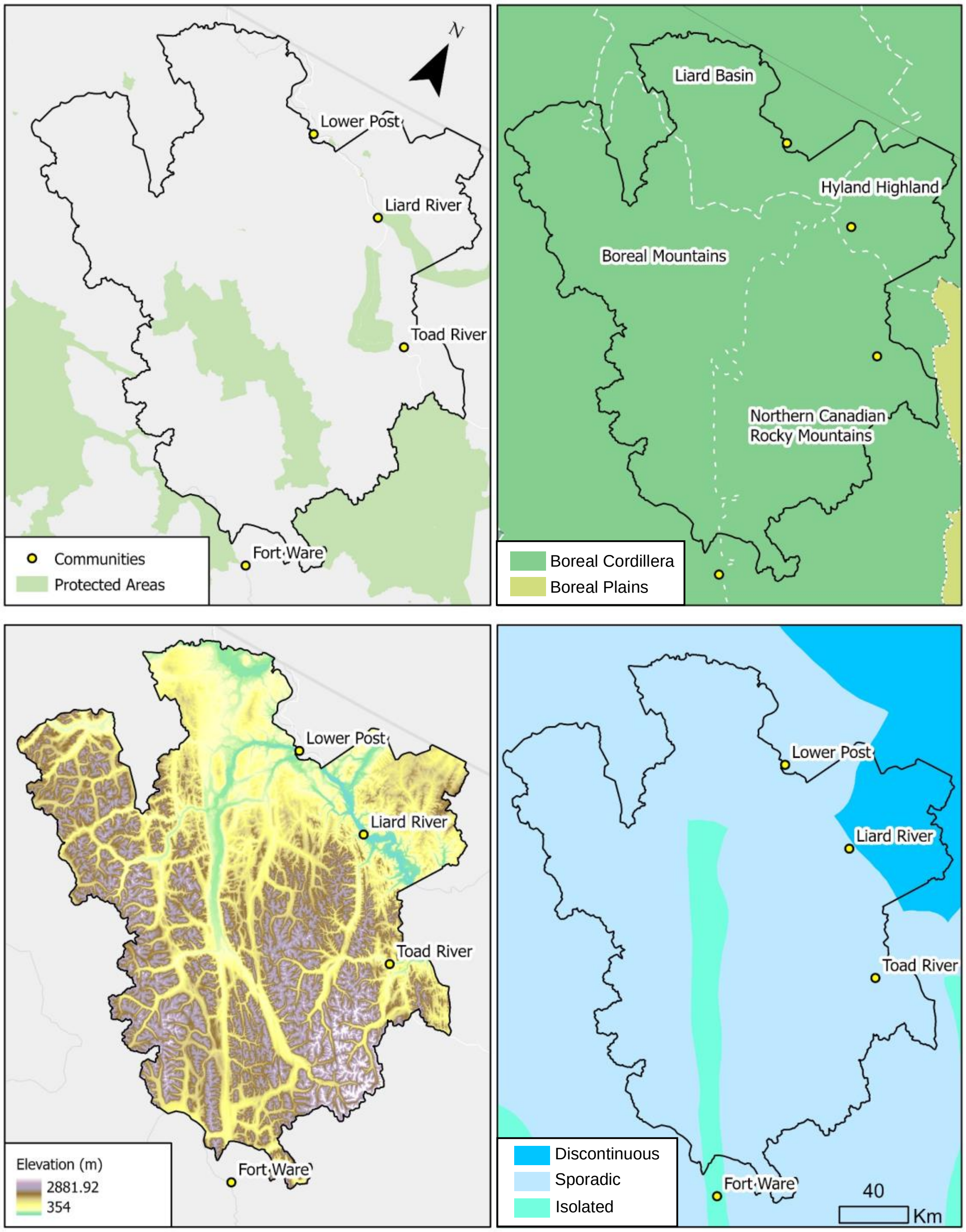

Figure 2. Top left: DKK project boundary. Top right: ecoregions (white dashed line) of the Boreal Cordillera and Plains ecozones found within the DKK region. Bottom left: topography in DKK. Bottom right: distribution of permafrost across the DKK area.

5.0 Methods

5.1 Satellite Imagery

This project used a fusion of multi-source and muti-temporal Earth Observation data of Sentinel-2 optical imagery, Sentinel-1 radar and topographic data (Merchant et al. 2019; Merchant et al. 2020). The advantages of Sentinel-2 satellite imagery includes its moderate spatial resolution (10 m), its large regional extent needed for a project of this scale, repeatable and standardized coverage, and 13 bands of spectral data. Moreover, this sensor includes near- and short-infrared, which are particularly sensitive to both vegetation and soil moisture content, and has proven useful for identifying water and wetland features. Sentinel-1 is also a moderate-resolution (10 m) sensor that emits microwave radiation and has all-weather, all day/night capabilities. Sentinel-1 imagery is highly sensitive to moisture conditions and thus landscape hydrological characteristics.

5.1.1 Optical Imagery: Sentinel-2

Sentinel-2 imagery was downloaded from the European Space Agency's (ESA) Copernicus Open Access Hub (European Space Agency, 2015). Image dates ranged from early July to late August from 2018-2019 (Table A1). The Level 1C products are composed of 100 km^2 tiles that have been orthorectified, radiometrically corrected to values of Top-of-Atmosphere (TOA), and spatially registered on a global reference system (UTM WGS 84 Zone 12N). Each image has 13 bands in total ranging in pixel resolutions of 10 m to 60 m. Images were then processed to Level 2A using the Sen2Cor algorithm via command line processing (Müller-Wilm, 2016). The processor performs tasks of atmospheric correction. Sen2Cor processing was applied to TOA reflectance products, and the main outputs were ortho-image Bottom-Of-Atmosphere (BOA) corrected reflectance images. Using the open-source software Sentinel Application Platform (SNAP), data preparation of BOA images included resampling of bands acquired at 20 m (i.e., bands 5, 6, 7, 8A, 11 and 12) to 10 m using a bilinear resampling method. Native 60 m resolution bands were not used beyond this point. Images were then mosaicked using ArcGIS (Figure 3).

5.1.2 Radar Imagery: Sentinel-1 and ALOS PALSAR

Sentinel-1 synthetic aperture radar (SAR) scenes were acquired from the Alaskan Satellite Facility (ASF) and Google Earth Engine (GEE), in ascending and descending orbits, with 250 km swath coverage at C-band (5.6 cm wavelength, 5.405 GHz), and in the Interferometric Wide (IW) beam mode (Table A2). Images were acquired as Level-1 Ground Range Detected products, with an incidence angle of ~38.1°. These are dual-polarized images containing a like-polarized band (vertically sent and vertically received; VV), and a cross-polarized band (vertically sent and horizontally received; VH).

Images from ASF were first speckle filtered with SNAP using a 3 x 3 window boxcar filter (i.e., mean filter) to reduce the inherent salt and pepper texturing, calibrated to sigma nought (σ°) to reduce data skewness and improve clustering potential, and corrected for residual thermal noise contributions. Images were then terrain corrected to compensate for distortions caused by topographical variations and satellite tilt using the range doppler terrain correction algorithm (Small & Schubert, 2008).

Images from GEE were speckle filtered using a 5 m smoothing radius to reduce the inherent salt and pepper. These images contained a like-polarized band (VV) and a cross-polarized band (VH). Once processed, the dual-polarized images were then exported in GeoTIFF format, mosaicked based on seasonal acquisition date, and had the cross-polarization ratio (VH/VV) computed (Figure 3).

ALOS PALSAR SAR scenes were acquired from ASF in Level 1.5 format, using the Vertex data portal (Table A3). Each image was acquired in fine beam dual polarization mode at L-band (23.62 cm wavelength, 1.27 GHZ) with HH and HV polarizations (horizontally sent and horizontally received, horizontally sent and vertically received). Images were taken at an incidence angle of 34.3° in ascending satellite orbit. ALOS PALSAR images were first speckle filtered using a 3 x 3 boxcar filter and then calibrated to values of sigma nought (σ°). Images were then resampled using a bilinear approach to 10 m, matching the other remotely sensed datasets. Lastly, the ALOS PALSAR scenes were mosaicked to create a seamless product, exported in GeoTIFF format, and the cross-polarization ratio (HV/HH) computed (Figure 3).

5.1.3 Topographic Data: Shuttle Radar Topography Mission

Topographic data from the Shuttle Radar Topography Mission (SRTM) was also included in the classification process. SRTM data was downloaded from the United States Geological Survey (USGS; NASA Shuttle Radar Topography Mission, 2013). This elevation model was generated using interferometric radar, which compares two radar images at different angles and signals. The difference between two signals allowed for the calculation of surface elevation. SRTM 1 Arc-Second global (30 m) with void filled data was downloaded and resampled to 10m. The geospatial analysis software Whitebox GAT (version 3.4) was used to compute elevation derivatives using the seamless DEM, including Topographic Wetness Index (TWI), Topographic Ruggedness Index, slope, aspect, and Height Above Nearest Drainage (HAND).

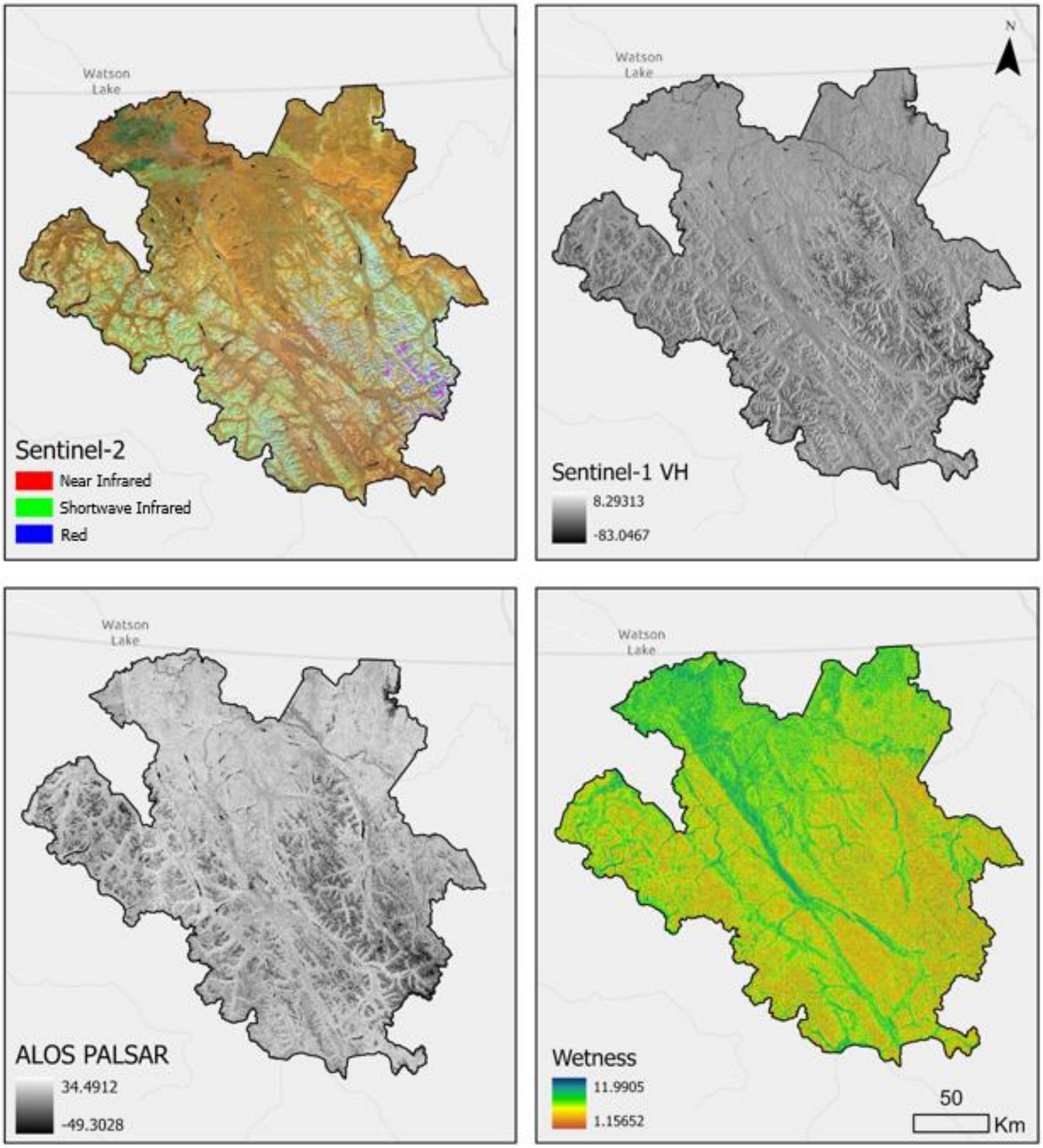

Figure 3. Visual overviews of the remotely sensed data catalogued for the DKK wetland mapping project: a) Sentinel-2, b) Sentinel-1, c) ALOS PALSAR, and d) TWI derived from the SRTM DEM.

5.2 Classification Scheme

A classification scheme (i.e., schema) categorizes the landscape features to be mapped; it is derived from the mapping product and features (or level of detail) that can be discerned from the source data (e.g., satellite imagery). A classification scheme consists of two critical components: 1) a set of class labels (e.g., open water, bog, fen, marsh, and swamp), and 2) a set of rules for assigning labels. The set of rules must be mutually exclusive, such that any given area falls into only one class, and totally comprehensive, such that the classification scheme includes an appropriate label for every area or feature within the designated project area (Congalton, 1991).

The classification scheme used for the DKK wetland mapping project was mapped to the EWC and conforms to the CWCS (Appendix B), which defines wetlands as areas that are inundated or saturated at a frequency and duration that promotes the establishment of adapted vegetation and hydric soils (National Wetlands Working Group, 1997). Organic wetlands, often referred to as peatlands or muskegs, include fens and bogs and are characterized by organic deposits greater than 40 cm deep that build up slowly due to wet, cool conditions with little or no oxygen. Mineral wetlands include swamps, marshes, and open water systems, which are characterized by shallow organic deposits generally less than 30 cm deep containing more nutrient-rich water and soil. Both mineral and organic wetlands can be open, shrubby, or treed, and can be systematically broken down into five major wetland classes (refer to Appendix B for photos and additional descriptions).

Bogs are peatlands that receive water only through precipitation. They are nutrient poor systems that are isolated from groundwater and surface run-off. Bogs are stagnant, non-flowing systems characterized by low plant diversity, and dry surface and saturated subsurface conditions. All bogs have a thick ground cover of sphagnum mosses, with some containing stunted black spruce and low-lying ericaceous shrubs.

Fens are peatlands that receive water from a combination of precipitation, surface runoff, and groundwater. They are more nutrient rich than bogs because of surface and groundwater inputs, and have greater plant diversity. Fens have a complex hydrology with high water tables, and can transport large volumes of water and nutrients across the landscape, often connecting wetland systems over large distances. Vegetation communities within fens can vary widely based on the nutrient availability, but can contain stunted black spruce, tamarack, shrub birch, willow, sedges, cottongrass, and mosses.

Swamps are mineral wetlands that may have deeper peat soils in some settings. Swamps receive water from run-off, precipitation, and groundwater. They are commonly recognized as shoreline areas of streams, lakes and floodplains, but also occur as transitional areas between uplands and peatlands. Swamps have fluctuating water tables and are seasonally flooded. They have fertile soils that periodically dry out supporting a diversity of trees, shrubs and other plants. Swamps are distinguished from other wetlands and from upland forests by hummocky ground that may contain pools of water and by a canopy of water tolerant shrubs or trees.

Marshes are often a transition between open water and shorelines. They receive water from precipitation and associated run-off, groundwater, and stream inflow, and fluctuate seasonally. Common vegetation includes cattails, rushes, and sedges.

Open water systems consist of rivers, lakes, ponds, and creeks. They receive water from precipitation, run-off, groundwater, and other watercourses. They are generally permanently flooded, but may fluctuate seasonally resulting in exposed mudflats. Shallow open water wetlands are open water systems that have a water depth of less than two metres, and typically support vegetation such as pond-lily and submerged aquatic vegetation. Water depth was unable to be measured via remote sensing methods, and as such shallow open water wetlands were not distinguished from deep open water systems in this classification.

Uplands are defined as well drained areas that do not show evidence of pooling water, hydrophytic vegetation, or wet-altered soils. Uplands were sub-classified based on the dominant vegetation community, such as conifer (e.g., white and/or black spruce, pine), deciduous (e.g., birch, aspen, balsam poplar), barren (e.g., mountain slopes, exposed shoreline), and other (e.g., sparsely vegetated alpine).

The anthropogenic class refers to areas of human disturbance, such as town sites (e.g., roads, airstrips) that are apparent in the imagery. Similarly, the burn class captures areas in the imagery where ongoing or past wildfires have altered the spectral signature preventing accurate classification. All attempts were made to acquire cloud- and smoke-free imagery for the entire DKK wetland mapping region; however, parts of the imagery remained affected by cloud cover and subsequent shadows. For areas with significant cloud or shadow coverage that prevented the identification of surface vegetation, the area was instead classified as cloud or shadow, respectively.

5.3 Training and Testing Data

Data used to train (i.e., calibrate), and test (i.e., validate) the DKK classification was acquired through two methods: a) in-field collection and b) high-resolution photo interpretation by DUC remote sensing analysts.

5.3.1 In-Field Reference Sites

The in-field collection of reference sites included 450 polygons, all of which were validated via overhead helicopter surveying. Each of these sites were visited in late June 23rd – July 6th. Sites contained the following information, all of which were spatially registered to their associated polygon: a) photographs (Figure 4), and b) species presence, heights, and coverages. Additional site information was recorded by the field crew for some sites, such as soil characteristics or hydrological cues; this information was very beneficial for distinguishing landcover types, especially for classes that are more difficult to determine (e.g., treed swamps). This collection of information was then used to assign a landcover call to each polygon according to DUC's EWC data model (Smith et al. 2007).

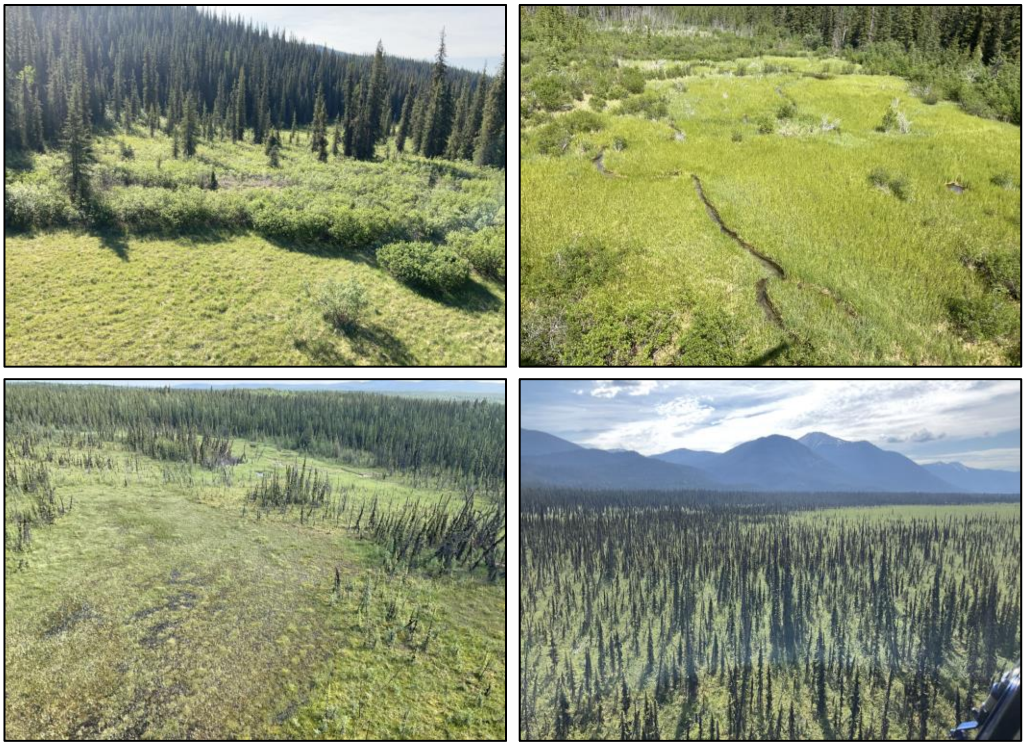

Figure 4. Field photo examples. Top left: shrub swamp; top right: meadow marsh; bottom left: graminoid rich fen; and bottom left: treed rich fen.

5.3.2 Photo Interpreted Reference Sites

Reference sites used for model training and testing were collected using high-resolution photo interpretation methods, and guided by an 11-class unsupervised classification using the ISODATA algorithm (i.e., corresponding to five wetlands classes, four upland classes, burn, and anthropogenic; Figure 5). Polygons (i.e., objects) corresponding to interpreted sites were obtained from an object-based segmentation of the Sentinel-2 optical imagery stack. Then, an experienced analyst selected objects in each wetland/upland unsupervised class, with each polygon needing to be within a single unsupervised cluster. This breakdown reflected the true proportions of the landscape, with a heavy focus on low-lying areas. This resulted in 2,678 polygons in total across the project area which were distributed to image analysts for interpretation.

Polygons also needed to be one hectare in size or greater, meeting the minimum mapping unit requirements of the Canadian Wetland Inventory (CWI). A total of 3,128 references sites were collected through the combined in-field and photo-interpretation approaches. Reference sites were then quality assured/controlled (QA/QC), and then split 70% into model training and 30% into model evaluation. The final number of samples for each class generally reflects the proportion of the class within, or near, the project area. Figure 6 is the spatial distribution of reference sites across the project area, and Table 1 is the tally of sites by EWC class.

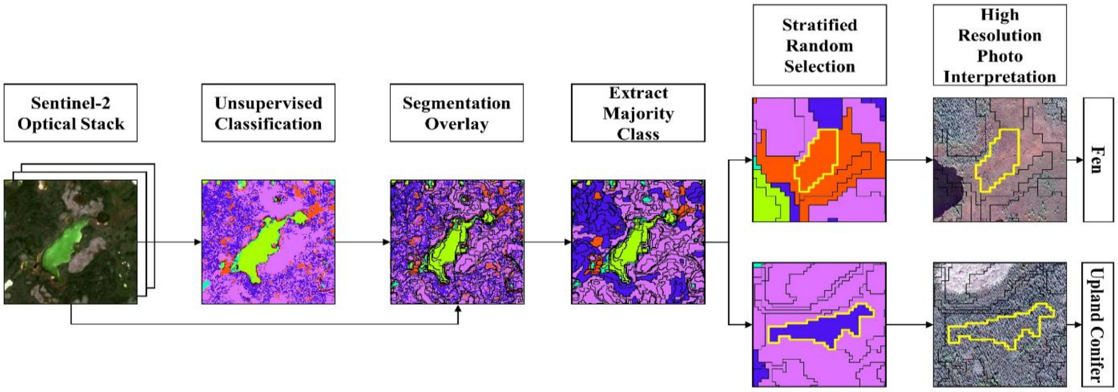

Figure 5. Site selection process for photo-interpreted reference sites.

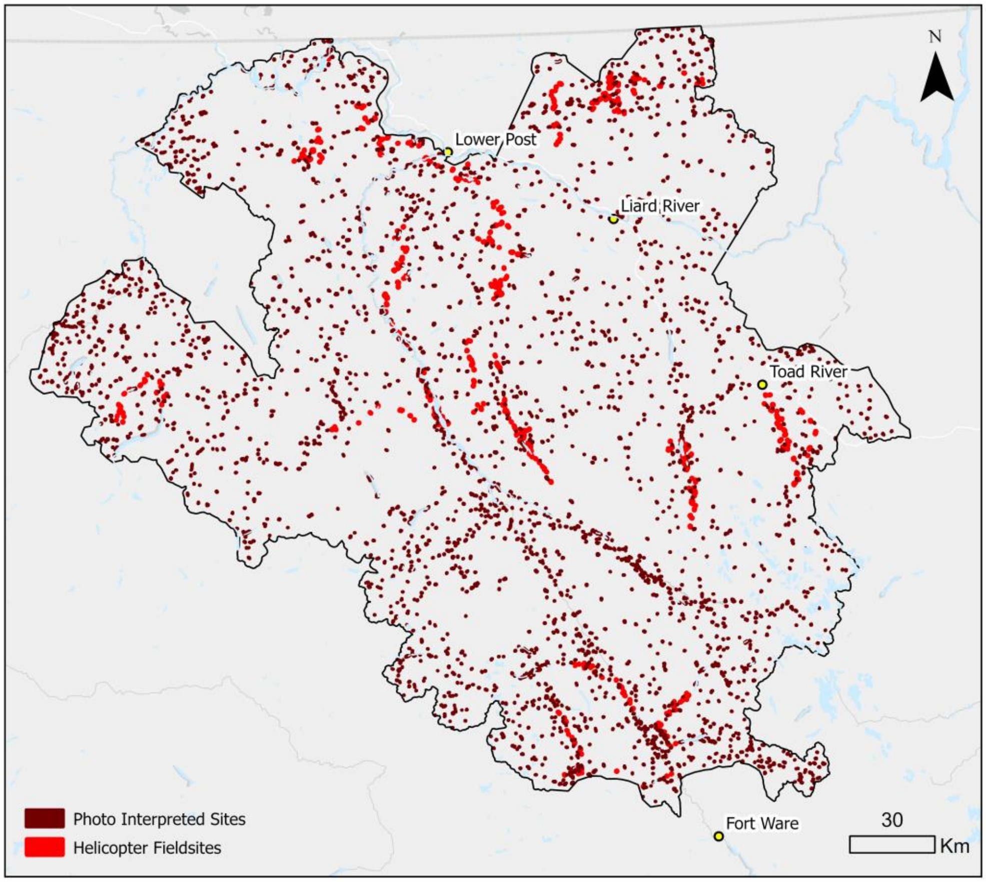

Figure 6. Reference sites (n = 3,128) collected for the DKK project area.

Table 1. Reference sites by EWC class. Note: not all classes were mapped due to the amount of photo interpreted sites.

EWC Class	**No. of Sites**
Open water	266
Aquatic bed	4
Emergent marsh	1
Meadow marsh	65
Graminoid poor fen	20
Shrubby poor fen	22
Treed poor fen	22
Graminoid rich fen	84
Shrubby rich fen	173
Treed rich fen	165
Treed bog	3
Hardwood swamp	15
Mixedwood swamp	7
Conifer swamp	27
Shrub swamp	103
Upland conifer	1127
Upland deciduous	12
Upland mixedwood	5
Upland barren	289
Upland shrub	350
Total	**3,594**

5.4 Classification

Two primary software packages were used for image analysis: ESRI ArcGIS Pro to handle data preparation, shapefiles and other ancillary datasets, and cartography, and eCognition 10.1 for primary image classification. The latter offers several advantages: (1) it allows for the processing of imagery datasets using a region-based approach, (2) it uses parameters such as shape, color, texture, and contextual information to aid in classification, and (3) it allows for the development of a knowledge base for the classification.

5.4.1 Generation of New Bands

Sentinel-2 imagery contains 13 bands of data, ten of which were used in the classification: three visible bands, three red-edge bands, two near-infrared bands, and two mid-infrared bands. Several additional indices (both mean and standard deviation) and transformations were added to help classify the imagery (Table 2). Sentinel-1 bands, which included VV and VH polarization backscatter, were ratioed to compute the cross-polarization ratio. Lastly, several topographic indices/variables were produced from the SRTM dataset using Whitebox GAT software (Table 2).

Table 2. Sensor bands and the variables/indices derived from each source.

Sensor/ Dataset	Band / Variable	Indices / Algorithm	Description
Sentinel-2	B2, B3, B4, B5, B6, B7, B8,B 8A, B11, B12	-	Sentinel-2 multispectral bands
Sentinel-2	EVI2	$2.5 * \frac{(B8 - B4)}{(B8 + 2.4 * B4 + 1)}$	Enhanced vegetation index 2
Sentinel-2	MNDWI	$\frac{(B3 - B11)}{(B3 + B11)}$	Modified normalized differenced wetness index
Sentinel-2	NDMI	$\frac{(B8 - B11)}{(B8 + B11)}$	Normalized differenced moisture index
Sentinel-2	NDVI	$\frac{(B8 - B4)}{(B8 + B4)}$	Normalized differenced vegetation index
Sentinel-2	SAVI	$1.5 * \frac{(B8 - B4)}{(B8 + B4 + 0.5)}$	Soil adjusted vegetation index
Sentinel-2	SRI	$\frac{(B8)}{(B4)}$	Simple ratio index
Sentinel-2	Principal Component Analysis (PCA)	-	PCA transforms an original correlated dataset into a smaller set of uncorrelated variables
Sentinel-1	BVV, BVH	-	Sentinel-1 linear polarizations
Sentinel-1	VH/VV	$\frac{(BVH)}{(BVV)}$	Sentinel-1 cross-polarization ratio
SRTM	DSM	-	Elevation
SRTM	Slope	$\sqrt{{D_x}^2 + {D_y}^2}$	DEM slope
SRTM	Aspect	$\arctan\left[\frac{D_y}{D_x}\right]$	DEM aspect
SRTM	TPI	$\left[\sum (x_{ij} - x_{00})^2\right]^{\frac{1}{2}}$	Topographic position index
SRTM	TWI	$\ln \frac{(As)}{(\tan * +Slope)}$	Topographic wetness index
SRTM	HAND	-	Height above nearest drainage

5.4.2 Segmentation

The first step in the classification procedure was the segmentation of the Sentinel-2 imagery into distinct regions known as image objects. Image objects are groups of pixels formed into a region based on a set of heterogeneity criteria (scale parameters, shape factor, compactness). The overall goal of the segmentation stage is to create image objects that are as large as possible, but as small as necessary to discriminate and map the enhanced wetland features. This allows for efficient processing of similar (i.e., homogeneous) areas in the landscape.

In object-based processing, the analyst uses spatial, spectral, and contextual information to derive the types of objects that will provide the building blocks for the classification. The quality of these objects is very important for the classification. If the boundaries of the image objects are not representative of the shapes of the wetland areas (e.g., narrow drainage features), then classification of the wetland areas will be difficult. At the same time, objects need to be large in homogenous areas. The objects filter out the spectral noise that does not correspond to change in wetland classes. Image objects thus work to maximize the capture of the signal and to reduce errors of omission, and they work to minimize the noise of the imagery and to reduce errors of commission.

Input bands for the segmentation process are indicated in Table 3. Equal weights were assigned to each optical band and two derived indices, and segmentation settings were the following: scale 50, shape 0.1, and compactness 0.5. For example, more weight or importance placed on one parameter lessens the importance of the other parameters. Scale controls the amount of variation within objects and therefore their eventual size, shape controls the weighting influence between shape and spectral color, and compactness is the ratio between the perimeter of the object and the square root of the area. Assigned parameters were based on extensive trial and error, analyst visual inspection, and expert experience.

Table 3. Image inputs and multispectral segmentation parameters.

Image Layers	**Weight**	
Sentinel 2 Band 2 - Blue	1	**Scale: 75** **Shape: 0.1** **Compactness: 0.9**
Sentinel 2 Band 3 - Green	1	
Sentinel 2 Band 4 - Red	1	
Sentinel 2 Band 5 – Red Edge 1	1	
Sentinel 2 Band 6 – Red Edge 2	1	
Sentinel 2 Band 7 – Red Edge 3	1	
Sentinel 2 Band 8 - NIR	1	
Sentinel 2 Band 8A - NNIR	1	
Sentinel 2 Band 11 - SWIR 1	1	
Sentinel 2 Band 12 - SWIR 2	1	

5.4.3 Classification Methodology

The classification scheme employed was based on the “Field Guide to the Wetlands of the Boreal Plains Ecozone of Canada” (Smith et al., 2007). The first step in the classification procedure was an initial processing aimed at delineating the major wetland classes in the imagery. Thus, the training polygons were used to identify open water, marsh, bog, fen, and swamp across the DKK region. To complete this first processing step, the imagery was classified using the random forest algorithm (Breiman, 2001), which has shown success in the literature in terms of efficiency and accuracy. Image object feature extraction, which fed the random forest classification process, included values of both the mean and standard deviation.

Once the major wetland classes were defined, the underlying detailed EWC classes were separated, again using the Random Forest algorithm. To do this, the initial major wetland classes were used as a mask to spatially limit the processing. For example, only objects classified as bog could then be reclassified as open, shrubby, or treed bog (Figure 7). The last step of image processing then involved class corrections using membership functions, for example data thresholding set up as conditional statements (e.g., > or <).

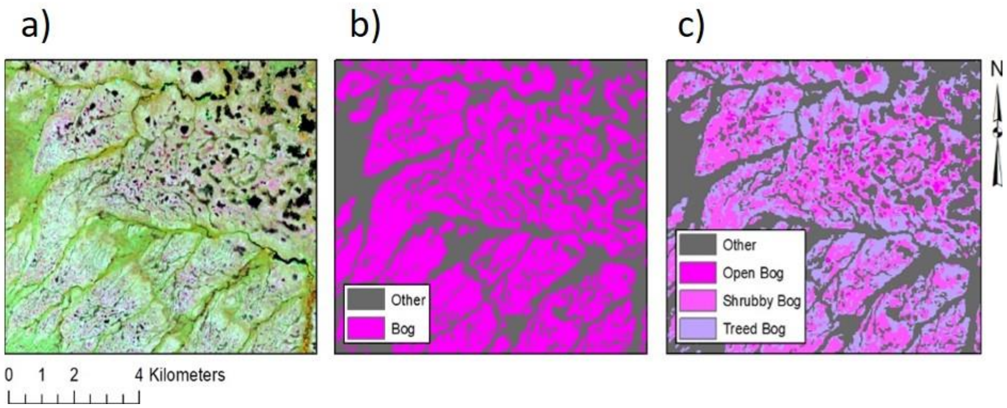

Figure 7. Example of spatial stratification by wetland class. The initial bog classification is used to reprocess the data into EWC classes. a) Sentinel-2 imagery, b) initial bog classification, and c) reprocessed EWC.

5.4.4 Manual Editing

The final step of the overall classification process was to correct the confused classes remaining after primary classification, and to make edits in areas with persistent classification errors. The editing of classification errors entailed comparing the classified image to the raw satellite image, field photos, and notes, in order to identify error. These errors were then corrected by manually changing the class value for the image objects that were classified in error. This step is critical to the accurate mapping of wetland areas, which vary greatly across the project area, exhibit a wide range of spectral variation, and often occur in high percentages of the land area. Application of the analyst's knowledge base via manual editing is often necessary to accurately delineate the more challenging wetland types/areas.

5.5 Accuracy Assessment

The accuracy assessment procedure compares the classification with reference data to estimate the accuracy of the final product. There are two primary motivations for accuracy assessment:

1) To understand the errors in the map (so they can be corrected), and
2) To provide an overall assessment of the reliability of the map (Gopal and Woodcock, 1992).

Classification accuracy was calculated for each landcover class by comparing the mapped class within each assessment site, to the site's class designation derived from the field campaign or photo interpretation. Evaluation metrics included overall map accuracy and kappa, and per-class metrics of user's accuracy, producer's accuracy, and F1 score. Overall accuracy is the proportion of correctly classified sites, kappa provides an evaluation of performance compared to a random assignment of values, user's accuracy compliments commission errors, producer's accuracy compliments omission errors, and F1 score is the harmonic mean of the user's and producer's accuracy. From these, F1 score is arguably the most meaningful metric because it accounts for imbalanced datasets (i.e., uneven counts of testing polygons), and simultaneously evaluates both errors of omission and commission.

A major assumption of quantitative accuracy assessments is that the label from the reference information represents the "true" label of the site, and that all differences between the remotely sensed map classification and the reference data are due to classification and/or delineation errors (Congalton and Green, 1993). Unfortunately, quantitative accuracy assessments can be inadequate indicators of map error because they often reflect non-map errors. Examples of the non-map errors that can cause confusion are:

1) Registration differences between the reference data and the remotely sensed map classification,
2) Digitizing errors,
3) Data entry errors,
4) Changes in wetland class between the date of the remotely sensed data and the date of the reference data,
5) Mistakes in interpretation of reference data, and
6) Variation in classification and delineation of the reference data due to inconsistencies in human interpretation of vegetation.

5.5.1 Error Matrix

An effective way to present accuracy assessment results is to produce an error matrix (Figure 8), also known as a confusion matrix, or contingency table. An error matrix allows the user to understand the classification accuracies of individual classes as well as the types of errors present in the classification. The matrix is designed as a square array with the columns representing the reference (field) data and the rows representing the classification data (Lillesand and Kiefer, 1994). The numbers within the array express the number of sites assigned to a particular class in the reference data relative to the number of sites mapped to a particular class in the classification. Numbers along the main diagonal of the matrix (grey cells in Figure 8) indicate an exact match between the reference data site and the map (i.e., correctly classified reference sites). Sites that have been designated as "false" (i.e., incorrectly classified reference sites) in the accuracy assessment are shown in the off-diagonal cells of the error matrix. Overall accuracy is calculated as the sum of the major diagonal cells (i.e., the correctly classified samples) divided by the total number of samples in the error matrix.

Example Error Matrix

		Reference Data					
		Class A	Class B	Class C	Class D	Row Total	User's Accuracy
Classified Data	Class A	28				28	100%
	Class B	2	10	4		16	63%
	Class C		4	13	2	19	68%
	Class D		1	3	8	12	67%
	Column Total	30	15	20	10	75	
	Producer's Accuracy	93%	67%	65%	80%		79%

Overall Accuracy = (28 + 10 + 13 + 8) / 75 = 79%

Producer's Accuracy		**User's Accuracy**
Class A	28 / 30 = 93%	28 / 28 = 100%
Class B	10 / 15 = 67%	10 / 16 = 63%
Class C	13 / 20 = 65%	13 / 19 = 68%
Class D	8 / 10 = 80%	8 / 12 = 67%

Figure 8. Error matrix example. Note that figure 8 is an example of an error matrix that is used to demonstrate the concepts discussed in this paragraph. Figure 8 does not present actual data associated with the EWC map produced in this project. The error matrices for this project are presented in Tables 9 and 10 of the Results section.

Errors of commission (inclusion) and errors of omission (exclusion) are both indicated in the matrix. A commission error occurs when an area (or reference site) is incorrectly classified as a category to which it does not actually belong. These are represented for the individual classes as the off-diagonal cells in the row under a particular class. An omission error occurs when an area is not classified to (or is omitted from) the correct category. These are indicated for a particular class in the off-diagonal cells along a column. Errors of omission are measured as the producer's accuracy, which is calculated as the total number of sites correctly classified for a particular class divided by the total number of reference sites for that class. Errors of commission are reported as the user's accuracy, which is calculated as the total number of sites correctly classified for a particular class divided by the total number of sites classified in that row (Story and Congalton, 1986; Congalton and Green, 1993). Every classification error is an omission from the correct category and a commission to a wrong category.

It is also important to consider that in some cases a site may have been allocated to a correct class purely by chance. To accommodate for this degree of chance, Cohen's Kappa coefficient (*K*) was also calculated from the generated error matrix (Cohen, 1960). *K* is a statistic that provides a measure indicating if the error matrix is significantly different from a random classified result, where values close to 1 indicate a strong agreement between the classified output and the reference data, and values close to 0 indicate poor agreement. The following equation was used to calculate K:

$$K = \frac{(Total\ Correctly\ Classified\ Sites - Expected\ Frequency\ )}{(Total\ Field\ Sites -\ Expected\ Frequency)}$$

where the expected frequency, which is the number of agreements that would have been expected by chance for each category, is calculated for each class as:

$$Expected\ Frequency = \frac{Row\ total * Column\ total}{Total\ Field\ Sites}$$

F1 score is the weighted average of user's and producer's accuracy.

$$F1\ Score = 2x\ \frac{User's\ x\ Producer's}{User's + Producer's}$$

Having a user's or producer's accuracy of 0 isn't desirable and will give a F1 score of 0 (the lowest possible score), which if both user's and producer's value is 1, F1 score of 1 indicates ideal values. F1 score ranges between 0-1.

6.0 Results

6.1 Final Classification

A total of 18 land covers (9 wetland classes, 5 upland classes, and 4 other classes) were mapped in the final DKK classification (Figure 9). Throughout the DKK project area, the occurrence of wetlands on the landscape is largely controlled by topographic position (i.e., wetlands form on level to gently sloping terrain). As such, the highest abundance of wetlands are found in valley bottoms. Valley wetland complexes were focal points for observable wildlife, especially beavers, moose, trumpeter swans, waterfowl (dabblers and divers), gulls, and terns. A description of each class appears in Appendix B at the end of the report. Table 4 presents the total percent cover and area in acres/hectares by class. The three most common, wetland classes are, treed rich fen (2.6%), open water (1.2%) and shrubby rich fen (0.9%). The most common upland class was upland conifer (48.8%). This mosaic is consistent with the analysis of available field data and photos, and reflects known regional patterns in soil, permafrost, hydrology, and topography.

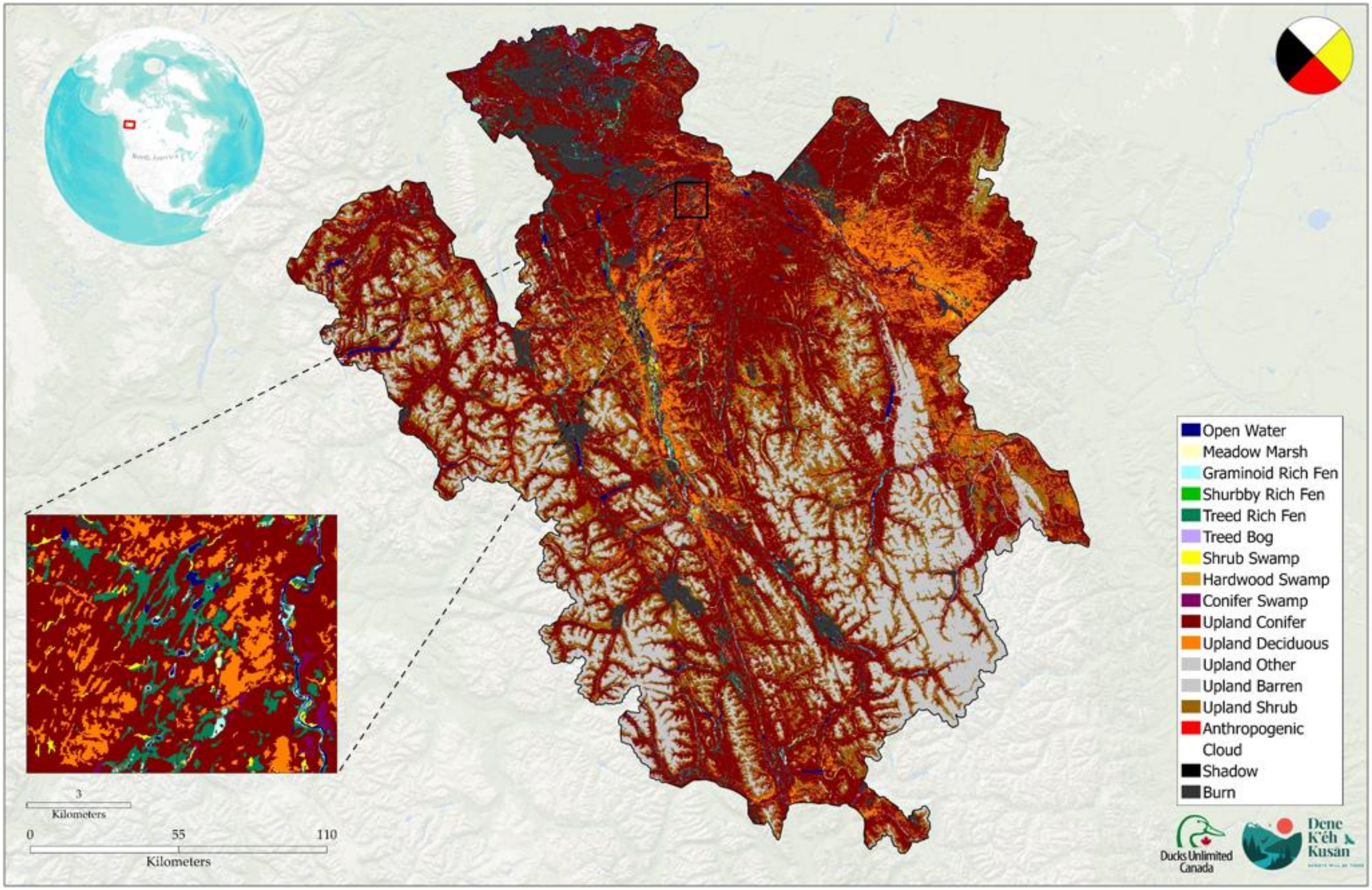

Figure 9. DKK EWC. Note that not all EWC classes were mapped due to field data and/or absence on the landscape.

Table 4. EWC area coverage for DKK project area. Note there is only a trace amount (less than 0.1%) of meadow marsh and treed bog.

Class	Acres	Hectares	Percent (%)
Open water	138,058	55,872	1.2
Meadow marsh	1,227	496	0.0
Graminoid rich fen	43,515	17,610	0.4
Shrubby rich fen	106,449	43,079	0.9
Treed rich fen	305,366	123,580	2.6
Treed bog	50	20	0.0
Shrub swamp	84,614	34,243	0.7
Hardwood swamp	6,381	2,582	0.1
Conifer swamp	69,007	27,927	0.6
Upland conifer	5,791,604	2,343,830	48.8
Upland deciduous	876,550	354,735	7.4
Upland other	23,011	9,312	0.2
Upland barren	201,9677	817,352	17.0
Upland shrub	1,878,889	760,376	15.8
Anthropogenic	5,179	2,096	0.0
Cloud	4,106	1,662	0.0
Shadow	5,410	2,189	0.0
Burn	505,087	204,406	4.3
Total Area	**3,109,663**	**1,258,435**	**100**

Note that the EWC was generated in a hierarchical format conforming to the CWCS, and thus the data can be consolidated into the five CWCS major classes: bog, fen, marsh, swamp, and open water. This was done in Figure 10, and in Table 5. For this CWCS summary, uplands were also consolidated into one class, as well as an "other" class, which represented the burn, cloud and anthropogenic areas.

Table 5. CWCS percent and area cover for the DKK area.

Class	Acres	Hectares	Percent (%)
Open water	138,058.5	55,871.5	1.16
Marsh	1,226.8	496.5	0.01
Fen	455,330.2	184,269.6	3.84
Bog	50.2	20.3	0.00
Swamp	160,001.7	64,751.8	1.35
Upland	10,589,731.0	4,285,605.3	89.26
Other	519782.5	210,353.1	4.38
Total Area	**1,1864,180.6**	**4,801,368.1**	**100**

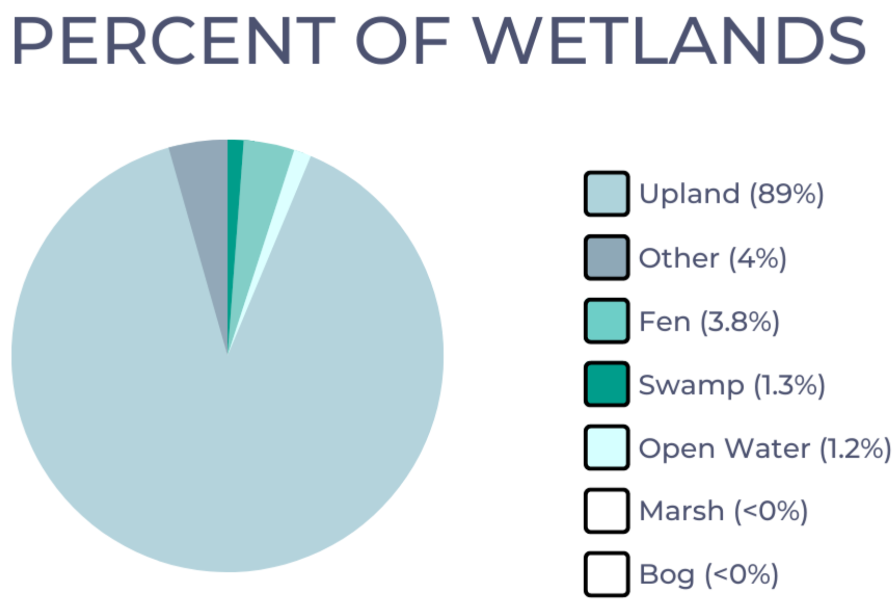

Figure 10. Percentages of the CWCS major wetland classes for the DKK project area.

6.1.1 Uplands

Upland areas comprise 89.26% of the DKK project area (Table 5, Figure 10). The general upland class includes upland conifer, upland deciduous, upland barren, upland shrub, upland other, and burn classes. Of these, upland conifer is most prevalent with 48.8% coverage. These sites are most often black spruce (*Picea mariana*) and jack pine (*Pinus banksiana*).

6.1.2 Fen

Fens occupy 3.8% of the landscape, making fen the most common vegetated wetland class in the project area. Fens have complex hydrology with high water tables that can transport large volumes of water and nutrients across the landscape. They are more nutrient rich than bogs, with greater plant diversity. In the DKK region, most fen systems were richer than expected (pH was generally above 7). Poor systems were sampled in the field, however, they did not exhibit as many poor vegetation indicators. Therefore, poor fens were not mapped in this project; instead, they were grouped into the rich fen group due to lack of data, however this doesn't mean they don't exist at all.

The most extensive EWC fen class is treed rich fen (2.6%), a peatland type covered by stunted black spruce (*Picea mariana*), tall shrubs, and moss species, along with a presence of tamarack (*Larix laricina*). Tamarack was seen in DKK region, however, were not consistent across the project area. The second most extensive EWC fen class is shrubby rich fen (6.9%) which are dominated by bog birch (*Betula pumila*), sweet gale (*Myrica gale*), and willow (*Salix spp.*). The presence of bog birch was used to differentiate fens from bogs across the study area. Bog birch indicates more mineral soil/water conditions, given the inconsistent distribution of tamarack across the DKK project, bog birch was the primary indicator to distinguish a bog from a fen. Shrubby cinquefoil and buckbean were flowering and used as rich fen indicators. Lastly, Graminoid rich fens were infrequent (0.4%).

6.1.3 Open water

Open water makes up 1.2% of the DKK landscape. Much of this class is bare open water, which includes lakes, rivers, and streams. Aquatic bed, saltflats and mudflats were rare and therefore, were not mapped. Aquatic bed, which is dominated by pond lilies (*Nuphar spp.*). Saltflats typically had little to no organic accumulation, and were mostly vegetation free except for pockets adjacent salt tolerant vegetation (e.g., foxtail barley; *hordeum jubatum*, alkali grass; *puccinellia*, etc.). Mudflats can be a temporally dynamic wetland class relative to the variation of seasonal hydrology.

6.1.4 Swamp

Swamps occupy 1.3% of the project area. Swamps are mineral wetlands that may have deeper peat soils depending on setting, with fluctuating water tables and are seasonally flooded. Shrub swamps are the most prominent of this class, covering 0.7% of the landscape. Shrub swamps, in this area, consist of at least 35% willow shrubs greater than 1-2m in height with bog birch. Some shrubs swamps had willow canopies less than 2m in height, and shrub swamp height appeared to be dependent on the valley, elevation, and local climate. Riparian conifer swamps (0.6%) and hardwood swamps (0.1%) were present along highly meandering streams and rivers with wide flood plains. These areas tended to have flood plains of silty soils not significantly raised from the meandering river/stream.

6.1.5 Marsh

Marsh, a mineral-based wetland class, occupy less than 0.1% of the study. Many valley marshes were associated with beaver systems. Beaver ponds were widely distributed in all valleys even in valleys dominated by coniferous trees. Marsh complexes were commonly found along the Kechika river valley and 20 km east of Crooked lake. Emergent marshes were rare in this area and were not mapped due to the lack of data. Meadow marsh in the area contained bluejoint reedgrass (*Calamagrostis candensis*) and sedges (*Carex spp*.).

6.1.6 Bog

Bogs were uncommon in the DKK project area (less than 0.01%). Bogs are nutrient poor peatlands that are often, although not always, isolated systems with low plant species diversity. Treed bogs are the most prominent bog type (less than 0.01%). Treed bogs are dominated by stunted black spruce and sphagnum moss (less than 20%), and a typical sparse shrub community of lab tea, short willow, cotton grass, sparsely distributed sedge.

6.1.7 Other Class

The DKK classification also contained an upland other class (4.4%), burned areas (4.3%), clouds, shadows, and anthropogenic (less than 0.1%). The upland other class consisted of streambeds, shorelines, and floodplains generally dominated by rock and gravel appeared to conform to the series of flood associations described in the BC wetlands guide (MacKenzie& Moran, 2004). That is, from the imagery these looked like potential swamp systems; however, in the field they were either low, middle bench, or high bench flood class. The extensive boreal wildfires that have impacted the region were visibly evident in the Sentinel-2 and -1 imagery, making classification of specific land covers within these areas difficult to impossible. Thus, polygons from the Canadian National Fire Database (2020) were used to mask out burn scars.

6.2 Accuracy Assessment

Accuracy assessments for this project are found in the error matrices below (Tables 6 and 7). The detailed EWC classification has an overall accuracy of 84% (0.77 kappa), and the general CWCS classification has an overall accuracy of 94% (0.87 kappa). A total of 986 reference sites were used for the accuracy assessment. This follows the splitting of reference polygons, approximately, 2/3rd for training and 1/3rd for assessment. Individual accuracies were calculated for a total of 10 EWC classes (Table 6) and three of the major CWCS wetland classes (Table 7). Note that some classes had a smaller number of assessment sites, relative to others, leading to the misrepresentation of accuracy percentages that are significantly higher or lower than their "true" values or no accuracy assessment (Tortora, 1978). These classes were under sampled as they are rare, and thus have a limited distribution across the project area.

Of the wetland classes, open water, shrubby rich fen and treed rich fen were mapped with the highest producer's accuracies of ~100% 76%, and 65% respectively. While, open water, conifer swamp and graminoid rich fen had the highest user's accuracies, ~98%, 75%, and 65%. Open water, treed rich fen and conifer swamp had the highest F1-score of 0.98, 0.61 and 0.60. The distinct spectral signatures of open water and upland barren also resulted in those classes being mapping with high per-class accuracies. Upland conifer also had a high user's, producer's and F1-score as this class represented most of the study area and has the most training and testing sites.

The classes with the lowest user's accuracy were shrubby rich fen (49%), and shrub swamp (52%). Fen classes displayed higher rates of confusion with other types of fens (i.e., the split of structural type) and swamp classes had confusion with uplands (e.g., due to similar spectral and structural characteristics).

Table 6. Error matrix for the detailed EWC classes.

	Open water	Graminoid rich fen	Shrubby rich fen	Treed rich fen	Shrub swamp	Conifer swamp	Upland conifer	Upland deciduous	Upland barren	Upland shrub	Row total	User's accuracy (%)	F1-score
Open water	**88**	1	0	0	1	0	0	0	0	0	90	98	0.98
Graminoid rich fen	0	**11**	5	0	0	0	0	0	1	0	17	65	0.39
Shrubby rich fen	0	17	**45**	17	7	0	0	1	0	4	91	49	0.57
Treed rich fen	0	4	7	**43**	5	1	6	4	0	3	73	59	0.61
Shrub swamp	0	1	2	3	**16**	1	0	7	0	1	31	52	0.50
Conifer swamp	0	0	0	0	0	**6**	2	0	0	0	8	75	0.60
Upland conifer	0	0	0	3	1	4	**373**	5	1	8	395	94	0.95
Upland deciduous	0	0	0	0	2	0	0	**66**	0	11	79	84	0.77
Upland barren	0	0	0	0	0	0	0	0	**70**	0	70	100	0.96
Upland shrub	0	0	0	0	1	0	7	10	4	**88**	110	80	0.78
Column total	88	34	59	66	33	12	388	93	76	115	964	--	--
Producer's accuracy (%)	100	32	76	65	48	50	96	71	92	77	--	--	--

Table 7. Error matrix for the CWCS major wetland classes.

	Open water	Fen	Swamp	Upland	Row total	User's accuracy	F1-score
Open water	**88**	1	1	0	90	98	0.98
Fen	0	**149**	13	19	181	82	0.88
Swamp	0	3	**23**	10	36	64	0.57
Upland	0	3	8	**643**	654	98	0.97
Column total	88	156	45	672	961	--	--
Producer's accuracy	100	96	51	96	--	--	--

7.0 Application and Limitations

7.1 Target Mapping Unit and Resolution

The target mapping unit (TMU) size is an estimate of the smallest feature (i.e., object) that can be consistently mapped and classified in the satellite imagery, and that the analyst attempts to map consistently (Dahl et al., 2020). The TMU also determines the minimum field or interpreted site that was used to both calibrate and validate the classification; in the case of the DKK wetland mapping project the TMU is 1 ha in size. For comparison, the Government of Alberta outlines a TMU of 0.9 ha for boreal wetland mapping (Alberta Environment and Parks, 2020), and a 2 ha TMU is used for the National Wetland Inventory in Alaska (Dahl et al., 2020). An appropriately sized TMU is important so that the analyst is able to accurately identify the general landcover class at each field site, and is simultaneously able to capture small or isolated features. The classification accuracy assessment is calculated using only sites greater than or equal to the TMU; however, the final classification itself may map landcovers smaller than the TMU. The classification assessment is done at the TMU level in order to minimize errors caused by noise and landcover heterogeneity, and thus provide a reliable assessment that reflects the satellite's sensor capabilities. Mapped classes smaller than the TMU are increasingly influenced by the noise inherent within remotely sensed imagery and may not always represent a meaningful landcover (e.g., mix of open water, marsh, and upland along a riverbank). Nevertheless, not all objects smaller than the TMU are errors, and are able to capture the true "on-the-ground" class. For example, some wetland classes, such as marsh, largely occur over areas less than 1 ha in the DKK project area, meaning only a small number of in-field reference sites were collected at the TMU. The analyst still mapped this class where possible using spectral information and landscape position; however, marsh was not included in the final accuracy assessment. Caution should be taken when assessing very small features (e.g., a few pixels), or comparing against on-the-ground surveys.

Additionally, remotely-sensed inventories are limited by the spatial resolution (i.e., the linear dimensions of each pixel) of the satellite imagery used to produce the classification. In the case of the DKK wetland mapping project, features smaller than the 10 m by 10 m pixel size of the satellite imagery would not be uniquely captured, and instead be combined with its surrounding features. While a 10 m by 10 m feature would theoretically be captured in the imagery used, multiple pixels are usually needed in order to reliably detect and interpret what is seen in the imagery.

7.2 Interpreting Classification Accuracies

Accuracy assessments are a common metric from which different classifications can be compared. However, overall accuracy statistics have been shown to be at times misleading or overemphasized when it comes to assessing the actual real-world validity of the map (Shao et al., 2019). Overall accuracy statistics are influenced by the number of classes and their complexity, class occurrence, amount and distribution of validation sites, purity and quality of validation sites, and mapping extent. Variations in these parameters can make it difficult to statistically compare different classifications one-to-one. Additionally, overall accuracy does not account for errors inherent in the data used to produce the map, such as image resolution, mapping scale, image quality, season of imagery (e.g., leaf-on or leaf-off), date of imagery (e.g., old or recent), type of imagery (e.g., optical, SAR, derivative), conditions during image capture (e.g., clouds, smoke, sun angle/position), availability of ancillary data, and ability to detect particular landcover types (Federal Geographic Data Committee, 2009). In the Standard for Terrestrial Ecosystem Mapping in British Columbia (Resources Inventory Committee, 1998), map accuracy is assessed both quantitatively (i.e., accuracy assessment) and qualitatively (e.g., visual inspection). Quantitative methods are used to provide some statistics on map accuracy, while qualitative methods are employed to assess whether the final map is reliable for its intended purposes.

Regardless of the limitations in reported overall accuracies, it is an often utilized statistic that should be used in conjunction with other measures, such as producer's and user's accuracies, to promote a comprehensive and transparent discussion on map accuracy. The producer's accuracy describes sites that were assigned the correct class label based on the ground truthed reference data (e.g., a site identified as a marsh in the field was mapped as a marsh in the classification), whereas the user's accuracy describes the likelihood of the assigned class being the true class (e.g., an area mapped as marsh in the classification is identified as a marsh when visited in the field). It is possible to have high producer's accuracies, but low user's accuracies if a class has significant errors of commission.

7.3 Application Scale

There are various theoretical spatial scales (e.g., local, regional, or national) at which inventories are developed and applied based on the intended purpose of the map. Local scale inventories or a site survey, are commonly produced using on-the-ground delineation methods and/or high-resolution satellite or aerial imagery with the goal of identifying small-scale features for detailed analyses. While these approaches produce the most accurate landcover information, the trade-off is that they are laborious, time consuming, and not scalable to larger areas. Regional scale inventories, such as the DKK wetland mapping project presented in this User's Guide, are produced using moderate resolution satellite imagery for the purposes of regional-based analyses, such as land-use planning and policy development. These inventories strike a balance between spatial extent, accuracy, time, and financial commitments. National scale inventories are produced at the national (or international) scale and aim to provide a very generalized understanding of landcover and associated processes across a wide geographic region. The user must understand at which scale they will be applying the data when choosing an inventory to work with. For example, a national- or regional-scale inventory would likely not be appropriate for determining the precise extent of wetlands present on a mining claim for regulatory purposes. Regional-scale inventories, however, are useful for understanding wetland extent and diversity within a watershed or ecoregion to assist in the development of policy and best practices.

7.4 Considerations for Use

The following points should be considered while using and interpreting the DKK wetland inventory presented in this guide:

- Regional-scale inventories are intended to be used at the landscape or watershed level for purposes such as LUP, watershed management, understanding of watershed-level processes, modelling, or indicating what areas may require further analysis.
- Regional-scale inventories are not intended for use at the local scale. This inventory does not replace the need for additional detailed wetland mapping at the local scale, such as for mine site assessment, urban development, or transportation corridors.
- Remotely sensed inventories are a "snapshot in time", meaning that they represent the landscape at the time of satellite image capture.
- The ability to map landscape features is limited by the spatial resolution of the satellite imagery used. In the case of the DKK wetland inventory, landscape features smaller than a single pixel (10 m by 10 m) in size are not visible in the imagery, and thus not able to be mapped. Multiple pixels are usually needed in order to reliably detect and interpret what is seen in the imagery.
- Wetlands occur along a gradient of conditions, and thus may vary in type (i.e., landcover class), and form (i.e., open, shrubby, treed) without distinct boundaries. Due to the methodology employed in the DKK wetland inventory, this product should not be used to derive specific wetland boundaries.
- Overall accuracy statistics do not perfectly describe real-world accuracy. When comparing multiple inventory products, user's should ensure that the product is reliable for its intended purposes (e.g., that the map with the higher overall accuracy does not have notable errors when visually examined).
- The purpose of this inventory was to identify wetlands on the landscape. While this inventory maps broad upland classes, they were not the focus of this product.

8.0 Conclusion

Satellite-based enhanced wetland mapping for the DKK region was completed for a ~3.9 million hectares area in northern British Columbia. Multi-date satellite imagery for this project was acquired from Sentinel-2, Sentinel-1, and ALOS PALSAR and was fused with topographic data from the SRTM. A total of 3,128 reference sites were collectively derived from helicopter-based wetland surveys and high-resolution photo interpretation. Object-based processing and machine learning classification techniques were applied to map 18 land covers (including 9 wetland classes). The EWC had an overall accuracy of 84%, while at the general CWCS detail the overall accuracy was 94%. The three most common, vegetated wetland classes are treed rich fen, shrubby rich fen and shrub swamp. At the general CWCS detail, open water comprised 1.2% of the landscape, followed by fens (3.8%), swamps (1.35%), marshes and bogs (less than 0.01%). The data products for this project include a digital EWC map, other digital and hardcopy maps, a complete database of field and photo-interpreted reference sites, and this User's Guide. These data will aid in the critical and continued process of conservation planning for this valuable and diverse area.

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Appendix A.

Earth Observation data of Sentinel-2 (Table A1) optical imagery, Sentinel-1 (Table A2) and ALOSPALSAR (Table A3) radar imagery

Table A8. Sentinel-2 optical imagery for the DKK wetland mapping project.

Date	Tile Name
07/09/2018	VXF
07/09/2018	VXG
07/09/2018	VCM
07/09/2018	VDM
07/26/2018	VCL
09/12/2018	VCL
07/26/2018	VDL
08/21/2018	VXD
09/10/2018	VVG
09/03/2018	VWG
08/11/2017	VWF
07/24/2018	VWE
07/24/2018	VXE
07/24/2018	VCJ
07/24/2018	VCK
07/27/2018	VWE
07/27/2018	VWG
09/12/2018	VCL
08/01/2018	VWG
07/09/2018	VWF
08/09/2019	VVF
08/09/2019	VVF
09/15/2018	VCL

Table A9. Sentinel-1 SAR imagery acquired for the DKK wetland mapping project.

Source	Acquisition	Path	Frame	Orbit
ASF	8/2/2019	137	192	Ascending
ASF	8/2/2019	137	187	Ascending
ASF	7/31/2019	108	191	Ascending
ASF	7/31/2019	108	186	Ascending
ASF	8/24/2019	108	191	Ascending
ASF	8/24/2019	108	186	Ascending
ASF	9/9/2019	137	192	Ascending
ASF	9/9/2019	137	187	Ascending
ASF	6/25/2019	108	191	Ascending
ASF	6/25/2019	108	191	Ascending
ASF	6/25/2019	137	192	Ascending
ASF	6/25/2019	137	187	Ascending
GEE	Late June 2019	N/A	N/A	Descending
GEE	Early July 2019	N/A	N/A	Descending
GEE	Early September 2019	N/A	N/A	Descending

Table A10. ALOS PALSAR SAR imagery acquired for the DKK wetland mapping project.

Date	Path	Frame
8/2/2010	220	1170
8/2/2010	220	1160
8/2/2010	220	1150
8/2/2010	220	1180
8/2/2010	220	1190
8/2/2010	220	1140
9/5/2010	222	1180
9/5/2010	222	1170
9/5/2010	222	1160
9/5/2010	222	1190
9/5/2010	222	1150
8/24/2010	224	1190
8/24/2010	224	1180
8/24/2010	224	1170
8/24/2010	224	1160
7/26/2010	225	1180
7/26/2010	225	1170
6/26/2010	218	1170
6/26/2010	218	1180
6/26/2010	218	1190
6/26/2010	218	1160
6/26/2010	218	1150
6/26/2010	218	1140
6/26/2010	216	1160
6/26/2010	216	1170
6/26/2010	216	1180
6/26/2010	216	1190

Appendix B.

Figure A.1 is the DUC EWC data model, which is adopted from "A Field Guide to the Wetlands of the Boreal Plains Ecozone of Canada" (Smith et al., 2007).

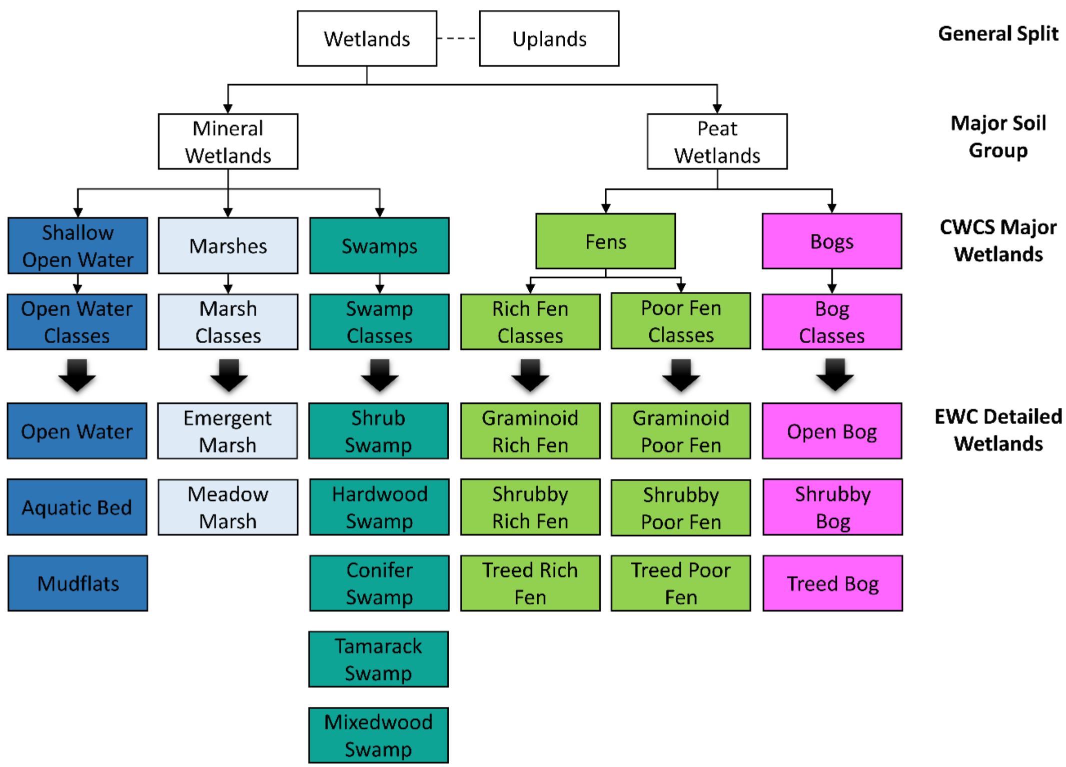


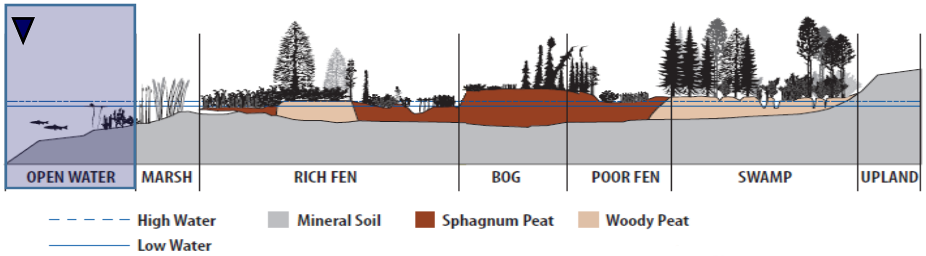
Figure B1. Hierarchal classification structure for the EWC. Note that not all of these classes were present in the DKK project area.

Description of the classes found in the DKK wetland mapping project.

Open Water

Open Water

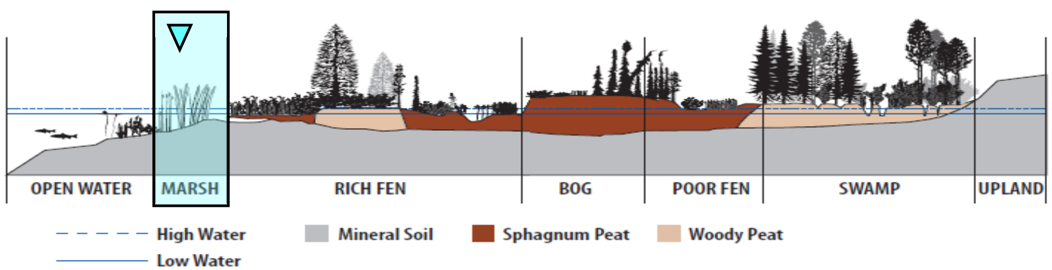
Areas where the water table is well above the ground surface most of the year. E.g., lakes, rivers, ponds



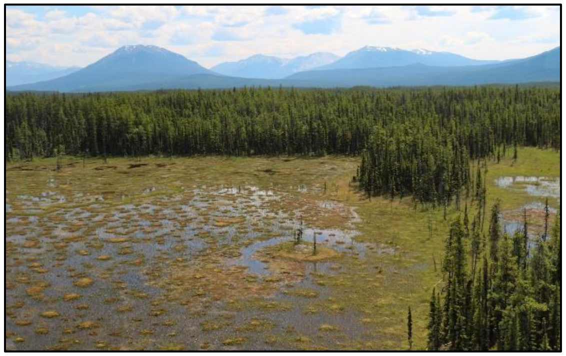
Marsh

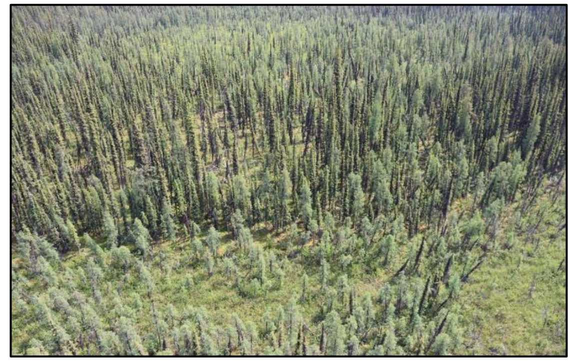
Meadow Marsh

Common along shorelines and is seasonally flooded. Water table significantly fluctuates, but is normally at or above the ground surface. Occurs in mineral soils, but can have shallow organic deposits.
Common Vegetation: beaked sedge, bluejoint grass



Fen





Graminoid Rich Fen

Complex hydrology with fluctuating water tables. Peat is greater than 40 cm. Sphagnum mosses cover <20% of area. Tree cover <25%, shrub cover <25% and <2 m tall.

Shrubby Rich Fen

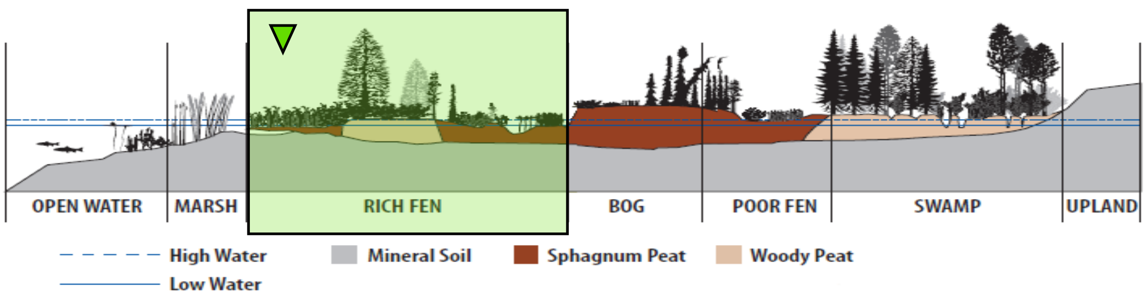
Sphagnum mosses cover <20% of area. Tree cover <25% and <10 m tall, shrub cover >25% and <2 m tall.

Common Vegetation: bog birch, sweet gale, willow, buckbean, wire sedge, brown moss.

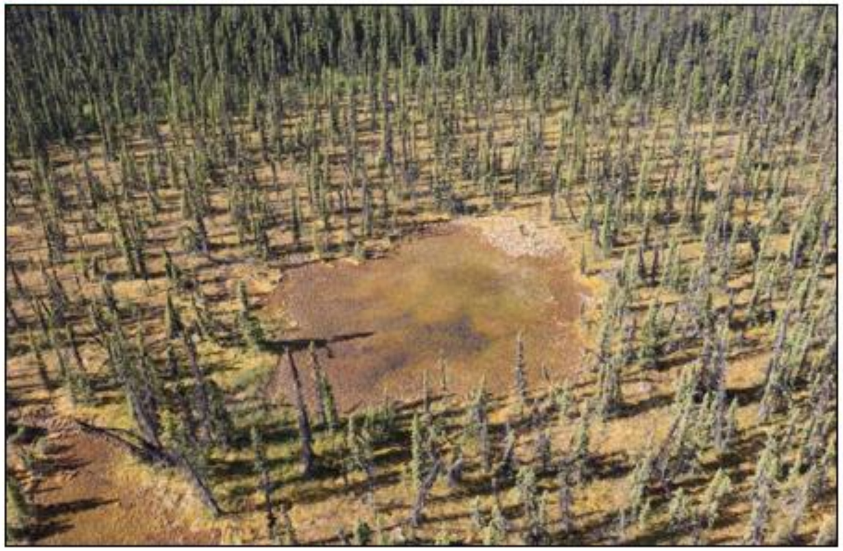
Treed Rich Fen

Sphagnum mosses cover <20% of area. Tree cover >25% and <10 m tall. Tamarack constitutes >5% of the trees.

Common Vegetation: black spruce, tamarack, sweet gale, bog birch, willow, brown moss.



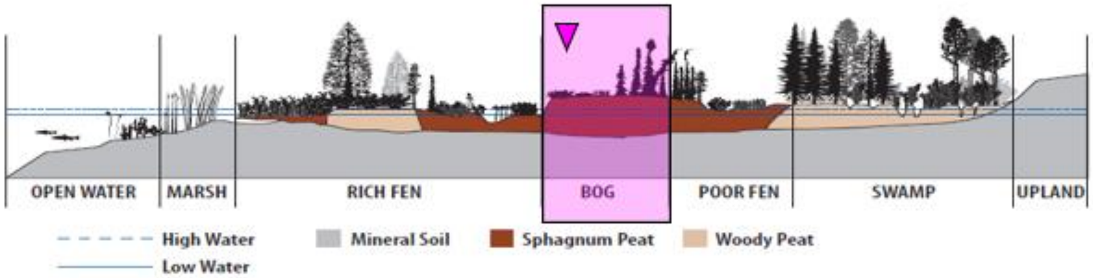
Bog



Treed Bog

Nutrient poor and acidic. Peat is >40 cm in depth. Sphagnum mosses cover >20% of area. Tree cover >25% and <10 m tall, where tamarack constitutes <5% .

Common Vegetation: black spruce, ericaceous shrubs, cotton grass, sphagnum moss.

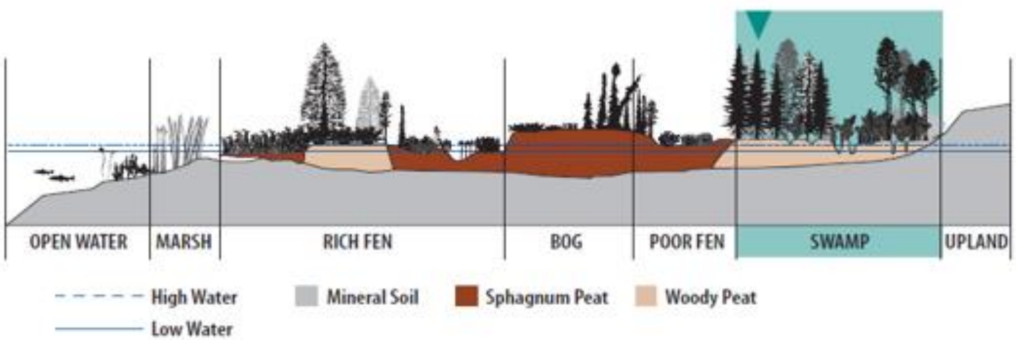


Swamp

Shrub Swamp
Seasonally fluctuating water tables with pools of water and hummocky ground. Organic layer is <40 cm in depth. Transition between uplands and wetlands. Found in riparian areas or places of beaver activity. Shrubs cover >25% of the area and are >2m. Common Vegetation: willow, speckled alder, broad-leaved sedge, bluejoint grass.

Conifer Swamp
Seasonally fluctuating water tables with pools of water and hummocky ground. Organic layer is typically <40 cm in depth,. Riparian areas. Black spruce dominant stand; >60% coverage and >10 m tall. Common Vegetation: black spruce, labrador tea, leather leaf, mosses.

Hardwood Swamp
Seasonally fluctuating water tables with pools of water and hummocky ground. Organic layer is <40 cm in depth. Found in riparian areas. Birch or balsam poplar dominant stand; >60% coverage and >10 m tall.
Common Vegetation: birch, balsam poplar, willow/red-osier dogwood/ alder understory.



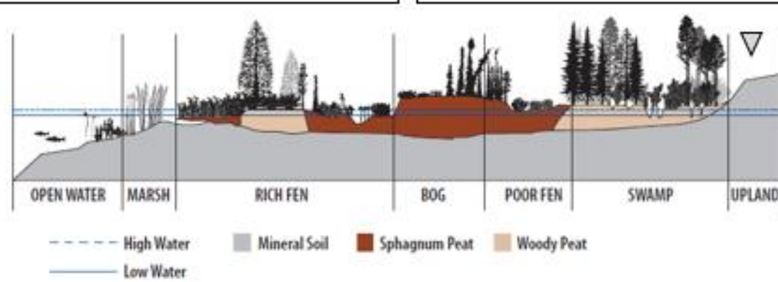
Ducks Unlimited Canada

Upland Conifer

Forested upland area where tree cover is 25 – 100% of the total area. Conifer species greater than 75%. Common Vegetation: black and white spruce

Upland Deciduous

Forested upland area where tree cover is 25 – 100% of the total area. Deciduous species > 75%. Common Vegetation: aspen, birch, willow

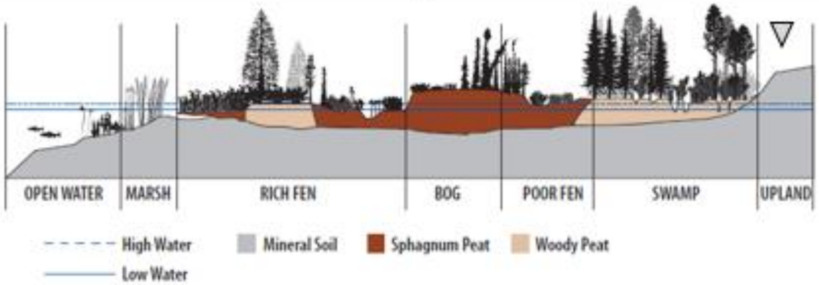


Upland Barren

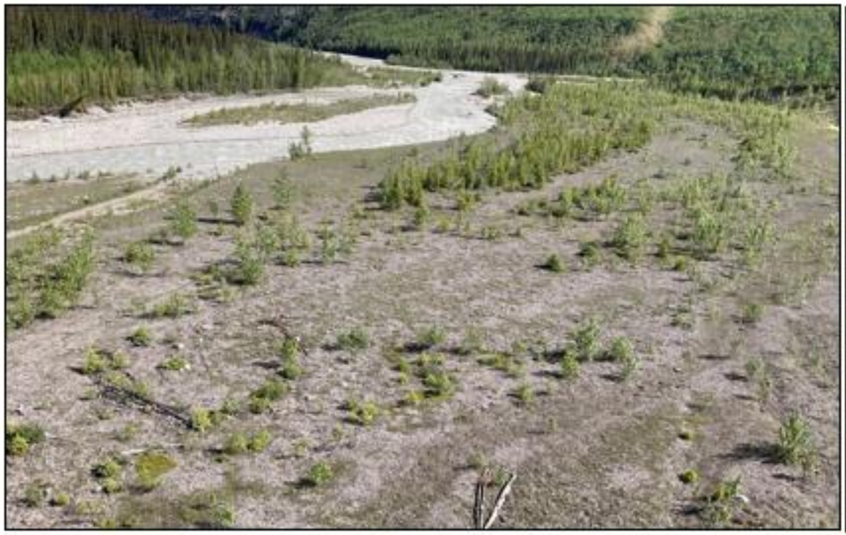
Tree cover < 25% and Barren > 50%
i.e., Rock, Gravel, Outcrop

Upland Shrub

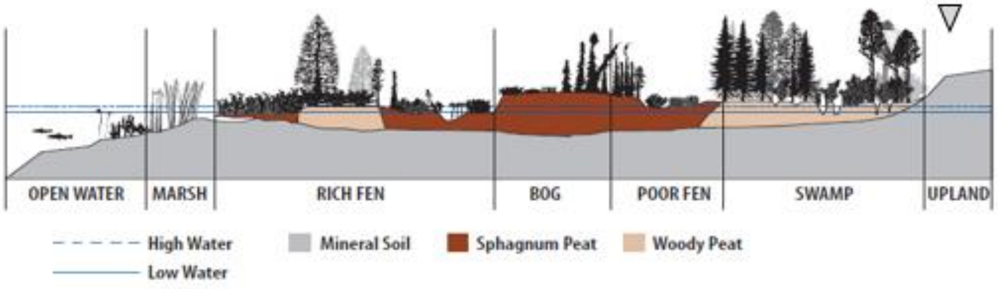
Tree cover < 25%, Shrub cover >25%,
Barren < 50%, and Lichen < 50%



Upland Other



Non-forested landcovers.
E.g. sandbanks, exposed rock/gravel, prairies.



Burn

Areas affected by fire with standing dead, fallen trees or burnt vegetation. Vegetation can be at various stages of regrowth. An area is classified as burn if the boundary of the burn is distinct.

Anthropogenic

Areas of >50% urban development.
i.e. cities, roads, airstrips