Forage Biomass and Vegetation Maps for the Alphabet Hills

Map User Guide and Accuracy Assessment

Version 1.0 (March 2023)

Version 1.0 forage biomass maps for Alphabet Hills derive from the Version 1.0 (May 2021) *Continuous Foliar Cover of Plant Species and Aggregates in North American Beringia*[1]. Version 1.0 relates to a modified U.S. National Vegetation Classification (USNVC) Version 2022-05-01.

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Cover photograph:

Survey team measures wet weights for simulated bite samples of *Salix pulchra* in the Alphabet Hills.

Contents

Tables

Figures

Introduction

In 2004, wildlife and land managers conducted a prescribed burn in the vicinity of the Alphabet Hills and west fork of the Gulkana River (hereafter referred to as the "Alphabet Hills study area") to improve habitat for moose (*Alces alces*) and other wildlife. To help determine the effects of the prescribed burn on forage availability for moose, the Alaska Center for Conservation Science (ACCS) at University of Alaska Anchorage collaborated with Alaska Department of Fish and Game (ADF&G) to sample biomass of forage plant species available for moose in burned and unburned portions of the Alphabet Hills study area during July and August 2021. Subsequently, we created a set of vegetation maps to enable spatially explicit sampling of statistical distributions of available forage biomass around peak growing season for moose. The vegetation maps extend site-level biomass measurements across the entire landscape of the study area. Table 1 provides an overview of the vegetation and related maps, representing conditions circa 2020, that we developed for the Alphabet Hills study area.

Table 1. Overview of vegetation and related maps produced for the Alphabet Hills study area.

Map name or category	**Dataset description**
Surficial features	Categorical map of non-vegetation surficial features that influence plant community composition and structure in the study area
Vegetation pattern	Predicted continuous foliar cover for 15 species or aggregates that relate to USNVC alliances
Existing vegetation type	Categorical map of vegetation types that relate to USNVC alliances
Forage biomass	Predicted continuous available forage biomass (dry mass) specific to moose for four common forage plant species and one species aggregate

In developing methods for mapping vegetation and available forage biomass in the Alphabet Hills study area, we applied four criteria to ensure that the resulting maps can be easily updated and expanded as needed in the future:

1. Scalable (can be expanded across moose range in Alaska)
2. Repeatable (can be re-mapped using consistent methods to assess change over time)
3. Consistent (facilitate comparisons among disparate regions)
4. Flexible (can adapt to future changes in USNVC to facilitate temporal comparisons)

Methods

The map products that we developed for the Alphabet Hills study area follow the standard set by the Federal Geographic Data Committee (FGDC) that all vegetation maps relate to the U.S. National Vegetation Classification (USNVC; FGDC 2008). We followed the most recent version of USNVC available upon the publication date: version May 2022 (2022-05-01). Because the May 2022 version of USNVC includes inconsistencies and problems for the boreal domain, we modified the USNVC to follow a set of recommended alterations to groups and alliances (Flagstad et al. 2021). In addition to following the FGDC standard, the map products also follow the *Standards for Mapping Vegetation in Alaska Version 1.1 (August 2022)* set by the Alaska Geospatial Council (VTWG 2022). Appendix 1 provides an overview of all covariate source datasets used in map development.

The analyses presented in this user guide are possible because of the development of numerous software packages and platforms. We recorded specific, repeatable methods as executable scripts for every non-manual processing step so that the entire mapping workflow can be repeated or adapted to regions outside of the Alphabet Hills study area.[2] We conducted tasks using software as follows:

1. Spatial processing and manual delineation in ArcGIS Pro 3.0.3 with Python 3.9.11.
2. Spectral and textural data acquisition with Google Earth Engine (Gorelick et al. 2017) and the Anaconda 2022.05 distribution of Python 3.9.12 with Google API Python Client 2.66.0.
3. Data formatting using R 4.2.1 and RStudio 2022.07.1+554 with dplyr 1.0.9, stringr 1.4.1, and tidyr 1.2.0 (Wickham et al. 2019).
4. Statistical modeling in the Anaconda 2022.05 distribution of Python 3.9.12 with scikit-learn 1.1.2 (Pedregosa et al. 2011), pandas 1.4.2 (McKinney 2010), and numpy 1.21.5 (Harris et al. 2020).
5. Prediction raster conversion and raster data extraction using R 4.2.1 and RStudio 2022.07.1+554 with fasterize (Ross et al. 2022), raster (Hijmans 2022), and sf (Pebesma 2018).

Field Data Collection

During the summer of 2021, we visited five sampling grids by float plane for three days of sampling at each grid. We located sampling grids within the study area subjectively to cover the maximum amount of environmental variation while meeting the practical requirements imposed by transportation method and walking distance between field sites. Within each sampling grid, we generated sampling sites using a spatially balanced random survey design (Theobald et al. 2007) as implemented in ArcGIS Pro. Because moose within the Alphabet Hills study area primarily consume *Salix* species (Renecker and Schwartz 2007, McArt et al. 2009), we balanced our site selection according to a continuous foliar cover map of non-dwarf *Salix* species (Nawrocki et al. 2021) to capture gradients in plant community composition and structure that were likely to be most relevant to moose. In the field, we prioritized sampling sites that belonged to the same set of spatially balanced points to preserve the survey design. In some cases, however, logistical considerations necessitated that we visit sites from multiple sets of spatially balanced points. The study design enabled us to conduct a

[2] Script repository available at: https://github.com/accs-uaa/forage-biomass-alphabet-hills

spatially blocked cross validation to reduce optimistic bias in our accuracy assessment due to spatial autocorrelation.

At each site, we established a 12.5 m radius plot composed of six 10 m long transect lines spaced at 60° intervals and originating 2.5 m from the plot center (Figure 1). We collected data for the following forage plant species at each site: non-dwarf *Salix* species, *Alnus alnobetula* ssp. *fruticosa*, *Populus balsamifera*, *Populus tremuloides*, *Betula neoalaskana*, *Betula kenaica*, *Betula* cf. *occidentalis*, an aggregate *Betula nana/glandulosa*, and *Chamaenerion angustifolium*. We quantitatively measured absolute foliar cover of target forage plant species as the sum of unique species intersections in any canopy layer with an approximately 1 mm radius laser at 20 points along each of the six transect lines divided by the total possible number of unique intersections per plot. The absolute foliar cover derived from the line-point intercept is expressed as the percentage of the measured ground area covered by live plant material per plot.

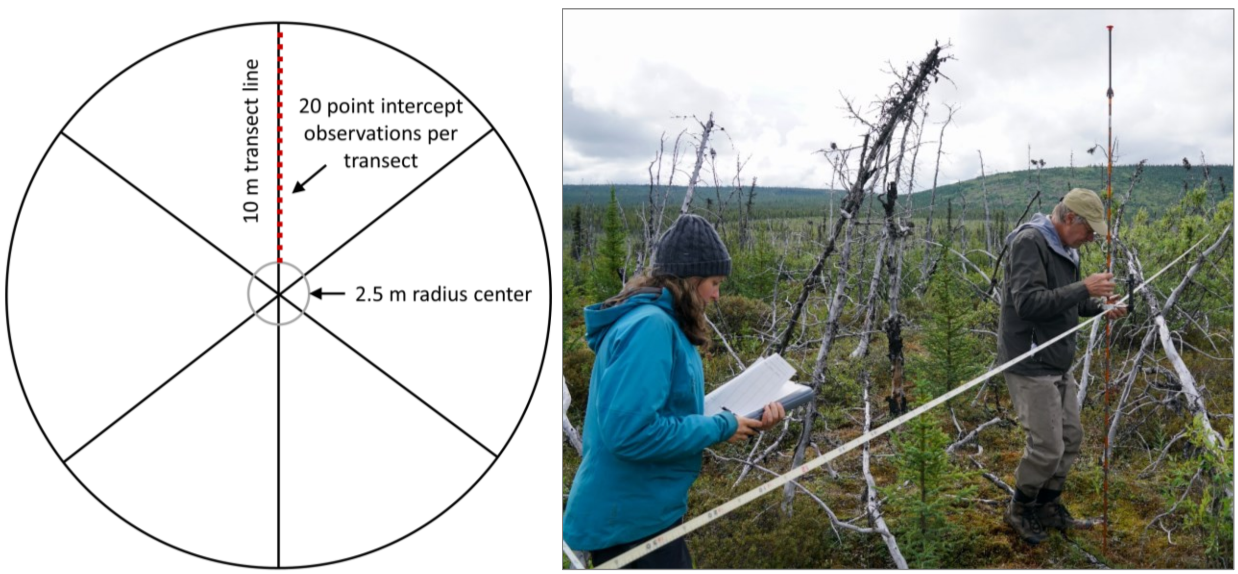

Figure 1. Diagram showing transect layout for 12.5 m radius line-point intercept plot and line-point intercept layout along one transect (left). Survey team conducts line-point intercept observations every 0.5 m along a transect line using a pole-mounted laser (right).

After measuring plot-level absolute foliar cover, we established 0.5 × 0.5 m subplots to quantify available forage biomass for each target taxon that occurred on or adjacent to each transect for a total of six subplots per taxon (or fewer where species occurrence limited sampling). We placed subplots on a representative portion of the target taxon according to a standard set of rules (i.e., to avoid biased sampling). Within each subplot, we estimated the total foliar cover of the target taxon, measured the maximum within-subplot height, and counted the number of bites of forage according to small-, medium-, and large-size categories based on expert opinion (Figure 2). At three subplots per taxon per plot, we measured the mass (wet) of the bite collections. We collected simulated bites at a single subplot within a subset of sites per sampling block. We also collected simulated bites opportunistically outside of sites but within the sampling block. To prevent sample degradation, we collected samples only on the same day or afternoon of the previous day of transport back from the field. We transported samples to the ADF&G Palmer Nutritional Lab where ADF&G ecologists measured dry mass for each sample. The combination of line-point intercept, subplot sampling, and biomass collections enabled us to scale the relatively fine scale biomass collection measurements to the plot-scale biomass necessary to map biomass across the landscape (see Forage Biomass methods below).

Figure 2. Survey team counts simulated moose bites per bite size category for *Salix pulchra*.

Image Segments

Alaska Department of Natural Resources (ADNR) provided Maxar and Spot imagery composites in accordance with license agreements. While the Maxar imagery composite has higher resolution and more recent acquisition dates than the Spot imagery composite, it suffered from cloud and snow cover in portions of the Alphabet Hills study area. We manually masked cloud- and snow-obscured areas from the Maxar imagery composite and substituted data from the Spot imagery composite. The Maxar and Spot imagery are not radiometrically equivalent, and we did not perform any calibration between the two data sources. We did not, however, relate field sample sites directly to metrics from the image composite, mitigating the impact of any radiometric inconsistencies. After creating the image composite, we resampled it to a 2 × 2 m resolution to match the target resolution of our analysis.

Image segmentation is a process that groups contiguous areas with similar spectral properties. The resulting image segments (hereafter referred to as "segments") provide mapping units that reflect visible distinctions in surficial features or plant communities. To produce segments, we loaded the combined imagery composite into Google Earth Engine (GEE) and calculated enhanced vegetation index-2 (EVI-2), normalized difference vegetation index (NDVI), and normalized difference water index (NDWI). We calculated segments (Figure 3) on the blue, red, green, near infrared, EVI-2, NDVI, and NDWI bands using simple non-iterative clustering (Achanta and Susstrunk 2017) as implemented in GEE. To ensure that we captured stream, river, and floodplain boundaries, we further divided the segments based on hydrologic parameters developed from manually digitized flowlines and the U.S. Geological Survey (USGS) 3D Elevation Program (3DEP) IFSAR 5 × 5 m Digital Elevation Model (DEM). Finally, we summarized numerous spectral, textural, topographic, hydrographic, and ancillary data to the segments as mean or standard deviation (see Appendix 1) to support the modeling processes that resulted in map products.

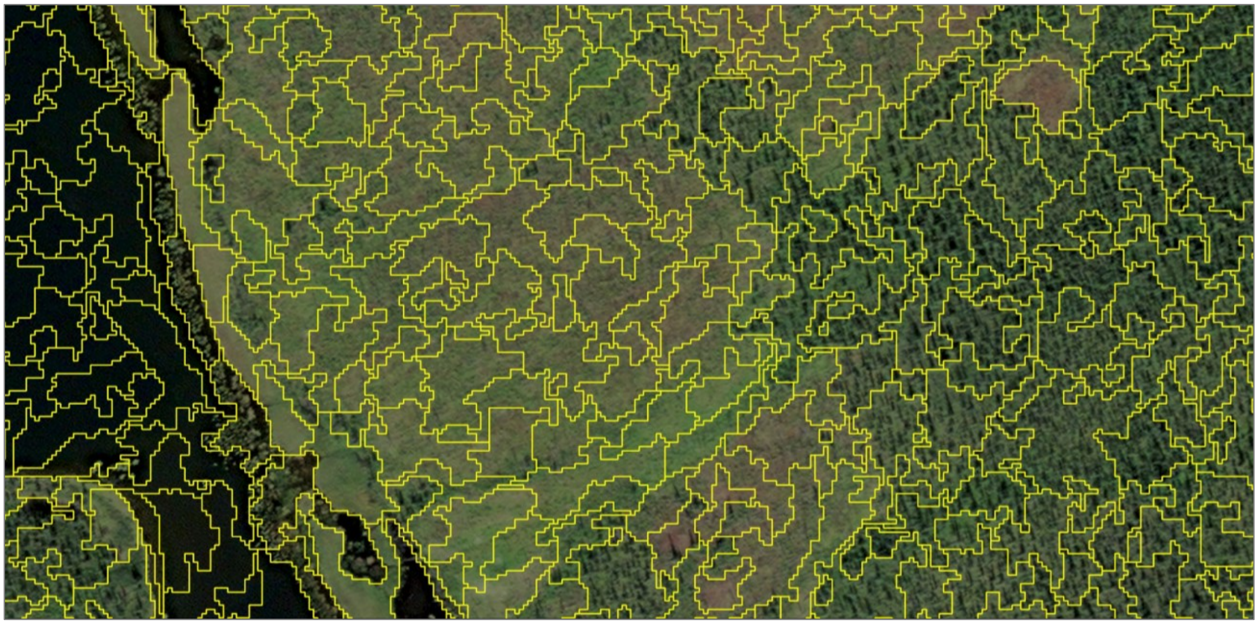

Figure 3. Example image segments calculated on the image composite with the ADNR Maxar composite (imagery ©Maxar 2021) shown in the background at 1:2,500 scale. Image segments group contiguous areas with similar spectral properties.

Minimum mapping unit

We calculated minimum mapping unit for the categorical datasets as the area covered by four of the coarsest pixels from source imagery. Since we relied on the Sentinel-2 system, the coarsest resolution imagery was 20 × 20 m, corresponding to a minimum mapping unit of approximately 0.5 acres. The minimum mapping unit is not relevant to the continuous maps and therefore applies only to the *surficial features* and *existing vegetation types*.

Surficial Features

To generate a training dataset of segments with class labels, we manually delineated *surficial features* by interpreting the Maxar and Spot imagery with a preference to Maxar when possible. Samples of all classes occur relatively equally across the Alphabet Hills study area; classes of specific types, however, are limited in occurrence by uneven distributions. We labeled *surficial features* for a total of 116,709 segments. We included an *aspen* class in the *surficial features* because we did not have a map of continuous *foliar cover* for *Populus tremuloides* to capture the aspen class through our standard programmatic key methods for *existing vegetation type* (see Appendix 2 for more details). The *aspen* class is relatively rare in the Alphabet Hills study area' we therefore manually delineated all *aspen* stands that we could identify in the imagery and then incorporated the manual delineations directly into the modeled results.

A random forest classifier statistically associated labeled segments with a suite of textural, spectral, topographic, and hydrographic covariates. Because the number of labeled samples depended on the rarity of the feature, we applied a class balance weighting equal to the inverse proportion of samples out of the total. We then predicted all segments from the trained classifier and converted the predictions to rasters. In addition to predicting the non-overlapping categorical *surficial features*, we also predicted overlapping probabilities for each *surficial feature*.

To reduce the potential for optimistic bias in model performance metrics because of spatial autocorrelation, we conducted a spatially blocked cross validation (see Macander et al. 2022) to estimate model performance. Spatial blocks were 10 × 10 km and did not overlap with one another. During each iteration of the cross validation, the labeled samples within a single spatial block were retained as independent test data (i.e., not used to train the classifier) such that labeled samples from each spatial block were predicted once. We calculated user's and producer's accuracy from the combined predictions of all cross validation iterations.

Vegetation Pattern

Foliar cover maps, which represent the distribution and abundance of species or ecologically narrow aggregates, in combination represent patterns of vegetation composition and structure (Nawrocki et al. 2020). Detailed methods and results for the production of the *foliar cover* maps are provided in Nawrocki et al. (2021). For the Alphabet Hills study area, we post-processed the *foliar cover* maps by summarizing them to segments, which downscaled the maps to match the resolution of our analysis. The number of mapped species and aggregates can be increased in a future map version following additional data integration to the Alaska Vegetation (AKVEG) Plots Database[3]. The expansion of mapped species for *foliar cover* is a necessary step to map *forage biomass* of additional forage plant species beyond those provided in this deliverable.

Existing Vegetation Type

Vegetation types in the USNVC are a particular set of opinions on major patterns of plant community composition and structure and geophysical characteristics. For this reason, we mapped *existing vegetation types* as a derivative of *vegetation pattern* and *surficial features*. First, we developed a schema relating USNVC alliances to mappable classes (see Appendix 3). We then created a programmatic key to the mappable classes based on the *foliar cover* values and assigned *surficial feature* per segment. The distributions for predicted *foliar cover* maps differ from those for foliar cover observed in the field. Thresholds in the programmatic key reflect the predicted distributions and may therefore sometimes differ from what might be most appropriate in a field key. Refer to the accuracy assessments for *vegetation pattern* and *surficial features*.

[3] Available: https://akveg.uaa.alaska.edu

Forage Biomass

To map forage biomass across the Alphabet Hills study area, we first scaled our field data from biomass collection measurements to per plot biomass. To do so, we calculated per bite mean dry mass for each bite size category per taxon across all collections. We then calculated the mean taxon foliar cover and number of forage bites per bite size across all subplots contained in each plot. To establish a scaling factor between subplots and plots, we calculated ground area coverage of each taxon within the subplots based on the mean estimated subplot foliar covers and within the plots based on the measured plot foliar cover. Multiplying the mean numbers of bites from the subplots by the plot- and taxon-specific scaling factors provided bite number estimates per plot. Finally, we multiplied bite counts by the per bite dry masses and summed the resulting masses for each bite size to arrive at total biomass per taxon per plot. To develop total biomass for the *Salix* forage aggregate, we summed all *Salix* species biomasses per plot.

The number of non-zero biomass observations in our training dataset varied per taxon. We eliminated all taxa with fewer than nine non-zero observations from any model attempts. For the remaining taxa, we calculated an appropriate number of covariates as the square root of the number of non-zero observations. The square root method is a conservative approach to preserve degrees of freedom for the model optimization and accuracy assessment necessary to develop a reliable map. Given a limited number of covariates per taxon, we selected a unique set of *vegetation pattern* and *surficial feature probability* covariates into each model based on known ecological relationships (e.g., the model for *Betula* shrub biomass included foliar cover of *Picea* because *Picea* and *Betula* shrubs commonly co-occur in the study area).

We modeled forage biomass using Bayesian linear regression with Ridge and LASSO regularization (see Hastie et al. 2009). Coefficient distributions were represented as gamma distributions to bias them towards zero and thereby reduce overfitting given our relatively small training dataset. In other words, the training data needed to exhibit a strong relationship to any particular covariate for the model to include an informative coefficient for that covariate. Ridge and LASSO regularization similarly biased coefficients towards zero to avoid overfitting. As with the *surficial features* model, we incorporated a spatially blocked cross-validation to avoid optimistic bias due to spatial autocorrelation in our accuracy assessment. We created 16 cross validation blocks along natural breaks in our sample sites from all five sampling blocks. Thus, we calculated accuracy metrics for forage biomass from the independent test partitions of 16 spatially blocked cross validation iterations.

Surficial Features

Surficial features delineate boundaries between different geophysical surface regimes (Table 2). We defined *surficial features* that relate to broad patterns of vegetation composition and structure within the Alphabet Hills study area. For example, *Salix* species along floodplains tend to be taller than those in surrounding lowlands while *Salix* species in the 2004 prescribed burn scar tend to be more diverse than those in the surrounding uplands (Figure 4). See Appendix 2 for the full map class schema for *surficial features*. The *surficial features* dataset is most appropriate for visual interpretation or data summarization, rather than statistical analyses.

Note: As described in the methods, we also included an *aspen* vegetation type in the *surficial features* model. Because the *aspen* class is relatively rare in the study area, the resulting producer's accuracy of the modeled *aspen* class was low. Therefore, we relied on manual digitization of the *aspen* class for the *surficial features* and *existing vegetation type* datasets rather than on the model results. Only the *surficial feature probability* for *aspen* relied on the model results.

Table 2. Metadata for the *surficial features* dataset.

Metadata	**Value**
Dataset filename	Alphabet_SurficialFeatures.tif
Dataset name	Surficial features
Data type	Categorical
Scale	1:24,000
Boundary resolution	2 × 2 m
Minimum mapping unit	0.5 acre
Coordinate system	Alaska Albers Equal Area Conic (EPSG 3338)
Units	N/A
Scale factor (modifies the units)	N/A
Theoretical unit range	Appendix 2
Time range	Circa 2020

The *surficial features* classes are mapped as mutually exclusive units. There are, however, some areas that include features smaller than the minimum mapping unit and other areas that are ambiguous between two or more classes. To capture gradients and ambiguities between classes, we provide the *surficial features* as the predicted probabilities for each class (Table 3). The predicted probabilities represent each *surficial feature* as a non-exclusive gradient; the *surficial feature probabilities* are most appropriate for statistical analyses, rather than visual interpretation or data summarization.

Figure 4. Example difference between two map classes of *surficial features*: *burned* (left) and *upland* (right; mapped as *upland/lowland*).

Table 3. Metadata for the *surficial feature probabilities* dataset.

Metadata	Value
Dataset filenames	1. Alphabet_Probability_aspen.tif
	2. Alphabet_Probability_barren.tif
	3. Alphabet_Probability_burned.tif
	4. Alphabet_Probability_drainage.tif
	5. Alphabet_Probability_floodplain.tif
	6. Alphabet_Probability_riparian.tif
	7. Alphabet_Probability_uplandlowland.tif
	8. Alphabet_Probability_water.tif
Dataset name	Surficial feature probability
Data type	Continuous
Scale	1:24,000
Boundary resolution	2 × 2 m
Minimum mapping unit	N/A
Coordinate system	Alaska Albers Equal Area Conic (EPSG 3338)
Units	Percentage prediction probability
Scale factor (modifies the units)	10
Theoretical unit range	0-1000
Time range	Circa 2020

Accuracy Assessment

Table 4 provides the user's and producer's accuracy for each map class. User's accuracy indicates the likelihood that the mapped class is accurate to the location in reality. Producer's accuracy is the percentage of observed samples that match the predicted samples. The full confusion matrix is provided in the model results of the project deliverable. All accuracies are based on number of segments rather than area to avoid overly optimistic bias in reported accuracies. Accuracies ranged from 76% to 100% (excluding a low of 27% for the *aspen* class because the end product relied on manual digitization).

Table 4. User's and producer's accuracies for each map class in the *surficial features* dataset.

Feature	**User's Accuracy (%)**	**Producer's Accuracy (%)**
barren/sparsely vegetated	95	89
burned	99	93
drainage	94	79
riparian	95	97
floodplain	97	97
water	100	100
upland/lowland	93	98
aspen	83	27

Vegetation Pattern

Vegetation pattern represents the distribution and abundance of plant species and aggregates that relate to USNVC alliances (Figure 5), per FGDC standards (FGDC 2008). We quantified *vegetation pattern* as percentage absolute *foliar cover* for 15 widespread, frequently dominant, or key plant species or aggregates (Table 5).

Table 5. Metadata for the *foliar cover* datasets.

Metadata	Value
Dataset filenames (xxxxxx = abbreviation)	Alphabet_Foliar_xxxxxx.tif
Dataset name (abbreviation)	1. Foliar cover of *Alnus* shrubs (alnus)
	2. Foliar cover of *Betula* shrubs (betshr)
	3. Foliar cover of *Betula* trees (bettre)
	4. Foliar cover of deciduous trees (dectre)
	5. Foliar cover of *Dryas* shrubs (dryas)
	6. Foliar cover of *Empetrum nigrum* (empnig)
	7. Foliar cover of *Eriophorum vaginatum* (erivag)
	8. Foliar cover of *Picea glauca* (picgla)
	9. Foliar cover of *Picea mariana* (picmar)
	10. Foliar cover of *Rhododendron* shrubs (rhoshr)
	11. Foliar cover of *Salix* shrubs (salshr)
	12. Foliar cover of *Sphagnum* (sphagn)
	13. Foliar cover of *Vaccinium uliginosum* (vaculi)
	14. Foliar cover of *Vaccinium vitis-idaea* (vacvit)
	15. Foliar cover of wetland sedges (wetsed)
Data type	Continuous
Scale	1:24,000
Boundary resolution	2 × 2 m
Minimum mapping unit	N/A
Coordinate system	Alaska Albers Equal Area Conic (EPSG 3338)
Units	Percentage absolute foliar cover
Scale factor (modifies the units)	1
Theoretical unit range	0-100
Time range	Circa 2019

Figure 5. The selected species or aggregates, such as wetland sedges (left; *Carex saxatilis* ssp. *laxa* (Trautv.) Kalela) and non-dwarf *Salix* shrubs (right; *Salix richardsonii* Hook.), relate to USNVC alliances.

Accuracy Assessment

The accuracy assessment for the *foliar cover* datasets includes multiple scales. Here, we provide R^2, mean absolute error (MAE), and root mean squared error (RMSE) at the site and landscape scales (Table 6). The R^2 provided here is a predictive measurement (as opposed to its typical use as a correlative measurement); it describes the amount of observed variation predicted by the model and can therefore range from $-\infty$ to 1. Depending on how the data are used or interpreted, different scales of assessed accuracy should be applied. The site scale accuracy pertains to comparisons in space or time of multiple sites (i.e., areas the size of 10 × 10 m grid cells or a single image segment to approximately 32,000 m^2 or 8 acres). The landscape scale accuracy pertains to summary comparisons of areas larger than approximately 32,000 m^2 or 8 acres. We calculated performance metrics from the merged independent test partitions of a 10-fold cross validation. The 10-fold cross validation from version 1.0 of the *foliar cover* maps was not spatially blocked. The resulting accuracy metrics may therefore contain some optimistic bias related to spatial autocorrelation. A spatially blocked cross validation will be incorporated into the next version of the *foliar cover* maps.

Table 6. R^2, MAE, and RMSE for *foliar cover* maps of 15 species and aggregates at the site scale, calculated for Interior Alaska, and the landscape scale, calculated for boreal and Arctic Alaska.

Map Group	**Site Scale**			**Landscape Scale**		
	R^2	MAE	RMSE	R^2	MAE	RMSE
Alnus shrubs	0.51	5.4	11.0	0.69	2.8	4.9
Betula shrubs	0.38	7.2	11.0	0.77	3.2	4.9
Betula trees	0.62	4.6	11.1	0.82	1.6	3.5
Deciduous trees	0.55	6.8	14.5	0.81	2.1	4.5
Dryas dwarf shrubs	0.34	3.8	9.4	0.65	1.7	3.3
Empetrum nigrum	0.41	3.5	6.3	0.74	2.0	3.5
Eriophorum vaginatum	0.58	4.9	10.5	0.70	2.2	4.2
Picea glauca	0.47	3.4	7.4	0.71	1.3	2.7
Picea mariana	0.47	4.2	8.7	0.70	1.4	3.3
Rhododendron shrubs	0.52	4.3	6.6	0.75	2.0	3.4
non-dwarf *Salix* shrubs	0.39	9.9	14.9	0.57	5.4	7.9
Sphagnum	0.48	6.3	14.8	0.64	3.9	6.8
Vaccinium uliginosum	0.53	5.3	8.5	0.77	2.2	3.7
Vaccinium vitis-idaea	0.44	2.9	5.8	0.58	1.6	2.7
wetland sedges	0.40	6.3	14.0	0.71	4.1	6.9

Existing Vegetation Type

Existing Vegetation Type is an abstraction of the dominant composition and structure of the plant community within a particular area (Table 7). In nature, plant communities are often heterogenous in composition and structure (Figure 6). The *existing vegetation type* map reduces all variation to homogenous and uniform clusters. Therefore, *existing vegetation types* are most appropriate for visual interpretation or data summarization. For statistical analyses, we recommend instead using the *foliar cover* or *forage biomass* datasets, which capture heterogeneity as gradients (see Nawrocki et al. 2020). Map classes for *existing vegetation types* relate to USNVC alliances (see Appendix 3), per FGDC standards (FGDC 2008).

Table 7. Metadata for the *existing vegetation type* dataset.

Metadata	Value
Dataset filename	Alphabet_ExistingVegetationType.tif
Dataset name	Existing vegetation type
Data type	Categorical
Scale	1:24,000
Boundary resolution	2 × 2 m
Minimum mapping unit	0.5 acre
Coordinate system	Alaska Albers Equal Area Conic (EPSG 3338)
Units	N/A
Scale factor (modifies the units)	N/A
Theoretical unit range	Appendix 3
Time range	Circa 2020

Area Results

Area by vegetation type provides a simple method to describe prevalence patterns of vegetation types within an area. To calculate *area by vegetation type* for a particular area of interest, the *existing vegetation type* raster can be extracted to the area of interest. Cell counts for each type in the extracted raster should be multiplied by 4 m^2 to get *area by vegetation type* in m^2. We provide the *area by vegetation type* summary for the Alphabet Hills study area (Table 8).

Table 8. Area and percentage (%) of total per *existing vegetation type* within the Alphabet Hills study area (2,119.1 km²; 523,641 acres). All values are rounded to the nearest decimal.

Existing vegetation type	Area (km²)	%	Existing vegetation type	Area (km²)	%
barren	29.8	1.4	mixed spruce (– Alaska birch)	230.9	10.9
sparsely vegetated	8	0.4	aspen / white spruce – aspen	0.4	0
water	110.2	5.2	birch	4.4	0.2
balsam poplar floodplain (white spruce)	0	0	alder – willow	92	4.3
white spruce floodplain	23.6	1.1	birch shrub – willow, mesic	398.2	18.8
alder – willow floodplain	1.5	0.1	birch shrub – willow, wet	136.9	6.5
black spruce, mesic	376.9	17.8	montane Dryas-ericaceous dwarf shrub, acidic	43.1	2
black spruce, wet	431.4	20.4	boreal sedge meadow, wet	20.7	1
white spruce – alder	30.3	1.4	boreal montane herbaceous	14.9	0.7
white spruce – birch shrub	119.1	5.6	boreal herbaceous	0.5	0
white spruce – willow	46.3	2.2	mixed spruce (– Alaska birch)	230.9	10.9

Figure 6. Existing vegetation types are abstractions of typically heterogenous plant community composition and structure. The example shown is classified as the *black spruce, wet* type, but the abundance of available moose forage is not homogenous within this vegetation type.

Forage Biomass

Forage biomass is the amount of food available to moose based on the abundance and structure of forage plant species. Forage is available to moose only if the animal would actually eat the plant material; for example, it precludes plant material that is guarded by dense woody stems (Figure 7). Our maps represent forage biomass for moose for four common forage plant species and one forage plant aggregate around peak growing season circa 2020 (Table 9). In combination with *surficial features* and *existing vegetation type*, the *forage biomass* maps could enable spatially explicit sampling from statistical distributions of forage biomass in nutritional models and may be informative in their current form for habitat or selection models.

Although numerous forage species occurred at least once in the study area, few species occurred frequently. Thus, some species lacked the minimum number of non-zero training samples necessary to produce a reliable map. Those species tended to also occur only at low abundances, presenting the further challenge of predicting a narrow range of variation. Additionally, the ecological specificity of the *vegetation pattern* datasets influenced which species could be mapped. Mapping individual *Salix* species has thus far been hindered by genus-level identifications for *Salix* in many vegetation survey and mapping datasets; thus, Nawrocki et al. (2021) mapped *foliar cover* for a non-dwarf *Salix* aggregate rather than for individual *Salix* species. Ongoing integration of vegetation survey data with high taxonomic resolution as well as new data collection will enable more ecologically specific *foliar cover* maps in the future. In turn, we expect that more ecologically specific *foliar cover* maps will enable production of *forage biomass* maps for additional *Salix* species. Appendix 4 provides a list of the forage species that we observed in the Alphabet Hills study area, but that we did not map in Version 1.0.

Figure 7. Much of the remaining current annual growth on the pictured *Salix glauca* is guarded by woody material and thus is not counted as available forage biomass.

Table 9. Metadata for the *forage biomass* datasets.

Metadata	Value
Dataset filenames (xxxxxx = abbreviation)	Alphabet_Forage_xxxxxx.tif
Dataset name	Dry available forage biomass density of: 1. *Alnus alnobetula* ssp. *fruticosa* (alnalnsfru) 2. *Betula* shrubs (betshr) 3. *Chamaenerion angustifolium* (chaang) 4. *Salix pulchra* (salpul) 5. Non-dwarf *Salix* shrubs (salshr)
Data type	Continuous
Scale	1:24,000
Boundary resolution	2 × 2 m
Minimum mapping unit	N/A
Coordinate system	Alaska Albers Equal Area Conic (EPSG 3338)
Units	g per m^2
Scale factor (modifies the units)	1
Theoretical unit range	0-∞
Time range	Circa 2020

Accuracy Assessment

Table 10 provides the accuracy for each *forage biomass* map as R^2, MAE, and RMSE. Additionally, we provide the mean and median dry forage biomass from non-zero sample sites as context necessary for the interpretation of MAE and RMSE, all of which share units of g per m^2. Based on the number and distribution of field training samples that we collected, we were only able to calculate a site scale accuracy. Thus, while landscape scale accuracy for *forage biomass* is likely higher than the site scale accuracy, we cannot quantify the landscape scale accuracy.

Table 10. R^2, MAE, and RMSE for *forage biomass* maps of four species and one aggregate at the site scale.

Taxon	R^2	MAE	RMSE	Non-zero Sites	Median Mass	Mean Mass
Alnus alnobetula ssp. *fruticosa*	0.19	6.3	13.9	9	16.7	25.6
Betula shrubs	0.5	10	13.9	65	10.6	19.7
Chamaenerion angustifolium	0.45	5.5	9.8	15	5.9	16.5
Salix pulchra	0.52	13	18.7	60	9.8	19.7
Salix shrubs (non-dwarf)	0.69	15	19.7	66	17.9	27.8

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Appendix 1: Mapping Covariates

Table 11 lists covariates used to develop the map products for the Alphabet Hills study area. For the development of the *vegetation pattern* (*foliar cover*) maps, refer to the user guide for the *Continuous Foliar Cover of Plant Species and Aggregates in North American Beringia*.[4] Map products are listed by number as follows:

1. Image segmentation
2. Surficial features
3. Existing vegetation type
4. Forage Biomass

The following conventions are used to denote additional clarifying characteristics pertaining to one or more datasets:

Ŧ Growing season median composite 2020-2022

ǂ 40-day median composites representing mid-June, late July, mid-August, and mid-September 2019-2022

* Maxar + Spot composite imagery

¶ Derived from manually digitized data

§ Derived from USGS 3DEP IFSAR Digital Elevation Model

** Source data from Nawrocki et al. 2021

ǂǂ Source data from Macander et al. 2022

Table 11. Textural, spectral, topographic, hydrographic, and other ancillary covariates represented biotic, abiotic, and anthropogenic gradients and features in models.

Type	Dataset (name abbreviation)	Original Resolution	Use
Mean	Sentinel-1 SAR Vertical-Vertical Polarization (vv)[Ŧ]	10 × 10 m	2
Mean	Sentinel-1 SAR Vertical-Horizontal Polarization (vh)[Ŧ]	10 × 10 m	2
Mean	Landsat 5/7 Burn Diff. Circa 2004 (burn_diff)	30 × 30 m	2
Mean	Sentinel-2 Band 2: Blue (s2_mm_02_blue)[ǂ]	10 × 10 m	2
Mean	Sentinel-2 Band 3: Green (s2_mm_03_green)[ǂ]	10 × 10 m	2
Mean	Sentinel-2 Band 4: Red (s2_mm_04_red)[ǂ]	10 × 10 m	2
Mean	Sentinel-2 Band 5: Red Edge 1 (s2_mm_05_rededge1)[ǂ]	20 × 20 m	2

[4] Nawrocki, T.W., M.L. Carlson, A.F. Wells, M.J. Macander, E.J. Trammell, F.D.W. Witmer, C.A. Roland, K. Baer, and D.K. Swanson. 2021. Continuous Foliar Cover of Plant Species and Aggregates in North American Beringia. Version 1.0 (May 2021). Available: https://doi.org/10.5281/zenodo.3897482

Type	Dataset (name abbreviation)	Original Resolution	Use
Mean	Sentinel-2 Band 6: Red Edge 2 (s2_mm_06_rededge2)ǂ	20 × 20 m	2
Mean	Sentinel-2 Band 7: Red Edge 3 (s2_mm_07_rededge3)ǂ	20 × 20 m	2
Mean	Sentinel-2 Band 8: Near Infrared (s2_mm_08_nearir)ǂ	10 × 10 m	2
Mean	Sentinel-2 Band 8a: Red Edge 4 (s2_mm_08a_rededge4)ǂ	20 × 20 m	2
Mean	Sentinel-2 Band 11: Shortwave Infrared 1 (s2_mm_11_shortir1)ǂ	20 × 20 m	2
Mean	Sentinel-2 Band 12: Shortwave Infrared 2 (s2_mm_12_shortir2)ǂ	20 × 20 m	2
Mean	Sentinel-2 Enhanced Vegetation Index-2 (s2_mm_evi2)ǂ	10 × 10 m	2
Mean	Sentinel-2 Normalized Burn Index (s2_mm_nbr)ǂ	20 × 20 m	2
Mean	Sentinel-2 Normalized Diff. Moisture Index (s2_mm_ndmi)ǂ	20 × 20 m	2
Mean	Sentinel-2 Normalized Diff. Snow Index (s2_mm_ndsi)ǂ	20 × 20 m	2
Mean	Sentinel-2 Normalized Diff. Vegetation Index (s2_mm_ndvi)ǂ	10 × 10 m	2
Mean	Sentinel-2 Normalized Diff. Water Index (s2_mm_ndwi)ǂ	10 × 10 m	2
Gridded	Composite Blue*	2 × 2 m	1
Mean	Composite Blue (comp_01_blue)*	2 × 2 m	2
Std. Dev.	Composite Blue (comp_01_blue_std)*	2 × 2 m	2
Gridded	Composite Green*	2 × 2 m	1
Mean	Composite Green (comp_02_green)*	2 × 2 m	2
Std. Dev.	Composite Green (comp_02_green_std)*	2 × 2 m	2
Gridded	Composite Red*	2 × 2 m	1
Mean	Composite Red (comp_03_red)*	2 × 2 m	2
Std. Dev.	Composite Red (comp_03_red_std)*	2 × 2 m	2
Gridded	Composite Near Infrared*	2 × 2 m	1
Mean	Composite Near Infrared (comp_04_nearir)*	2 × 2 m	2
Std. Dev.	Composite Near Infrared (comp_04_nearir_std)*	2 × 2 m	2
Gridded	Composite Enhanced Vegetation Index-2*	2 × 2 m	1
Mean	Composite Enhanced Vegetation Index-2 (comp_evi2)*	2 × 2 m	2
Std. Dev.	Composite Enhanced Vegetation Index-2 (comp_evi2_std)*	2 × 2 m	2
Gridded	Composite Normalized Diff. Vegetation Index*	2 × 2 m	1
Mean	Composite Normalized Diff. Vegetation Index (comp_ndvi)*	2 × 2 m	2

Type	Dataset (name abbreviation)	Original Resolution	Use
Std. Dev.	Composite Normalized Diff. Vegetation Index (comp_ndvi_std)*	2 × 2 m	2
Gridded	Composite Normalized Diff. Water Index*	2 × 2 m	1
Mean	Composite Normalized Diff. Water Index (comp_ndwi)*	2 × 2 m	2
Std. Dev.	Composite Normalized Diff. Water Index (comp_ndwi_std)*	2 × 2 m	2
Mean	Topography – Aspect (top_aspect)[§]	5 × 5 m	2
Mean	Topography – Elevation (top_elevation)[§]	5 × 5 m	2, 3
Mean	Topography – Exposure (top_exposure)[§]	5 × 5 m	2
Mean	Topography – Heat Load Index (top_heat_load)[§]	5 × 5 m	2
Mean	Topography – Position (top_position)[§]	5 × 5 m	2
Mean	Topography – Radiation (top_radiation)[§]	5 × 5 m	2
Mean	Topography – Roughness (top_roughness)[§]	5 × 5 m	2
Mean	Topography – Slope (top_slope)[§]	5 × 5 m	2
Mean	Topography – Surface Area (top_surface_area)[§]	5 × 5 m	2
Mean	Topography – Surface Relief (top_surface_relief)[§]	5 × 5 m	2
Mean	Topography – Wetness Index (top_wetness)[§]	5 × 5 m	2
Gridded	Hydrography – Rivers[¶]	2 × 2 m	2, 3
Mean	Hydrography – River Position (hyd_river_position)[§¶]	2 × 2 m	2
Mean	Hydrography – Stream Position (hyd_stream_position)[§¶]	2 × 2 m	2
Mean	Foliar cover of *Alnus* shrubs (fol_alnus)[**]	10 × 10 m	3, 4
Mean	Foliar cover of *Betula* shrubs (fol_betshr)[**]	10 × 10 m	3, 4
Mean	Foliar cover of *Dryas* shrubs (fol_dryas)[**]	10 × 10 m	3
Mean	Foliar cover of *Empetrum nigrum* (fol_empnig)[**]	10 × 10 m	3
Mean	Foliar cover of *Eriophorum vaginatum* (fol_erivag)[**]	10 × 10 m	3, 4
Mean	Foliar cover of *Rhododendron* shrubs (fol_rhoshr)[**]	10 × 10 m	3
Mean	Foliar cover of *Salix* shrubs (fol_salshr)[**]	10 × 10 m	3, 4
Mean	Foliar cover of *Sphagnum* (fol_sphagn)[**]	10 × 10 m	3
Mean	Foliar cover of *Vaccinium uliginosum* (fol_vaculi)[**]	10 × 10 m	3, 4
Mean	Foliar cover of *Vaccinium vitis-idaea* (fol_vacvit)[**]	10 × 10 m	3, 4
Mean	Foliar cover of wetland sedges (fol_wetsed)[**]	10 × 10 m	3, 4

Type	**Dataset (name abbreviation)**	**Original Resolution**	**Use**
Mean	Foliar cover of forbs (fol_forb)[ᵻᵻ]	30 × 30 m	3, 4
Mean	Foliar cover of graminoids (fol_graminoid)[ᵻᵻ]	30 × 30 m	3
Mean	Foliar cover of deciduous shrubs (fol_decshr)[ᵻᵻ]	30 × 30 m	3, 4
Mean	Surficial feature predicted probabilities	2 × 2 m	4

Appendix 2: Map Class Schema for Surficial Features

The map class schema for *surficial features* is intended to represent major groupings of geophysical features that provide additional geospatial information necessary or helpful to deriving *existing vegetation types* that relate to USNVC alliances. Additionally, we included a *burned* class to enable subsequent research to distinguish areas burned in the 2004 or 2013 fires from areas not burned within the past 50 years with high precision.

Barren/Sparsely Vegetated

Barrens are unvegetated surfaces with exposed mineral soil. In the Alphabet Hills study area, they occur from hydrologic erosion and deposition along rivers and in montane zones with poorly developed soils (Figure 8). Barrens along floodplains may be covered by surface water for part of the year when water levels are higher than the growing season median. The *barren* class includes both *barren* and *sparsely vegetated* vegetation types, which are split apart by amount of total plant cover present.

Figure 8. *Barrens* and *sparsely vegetated* areas interspersed with *boreal montane herbaceous* on a hill summit in the Alphabet Hills (imagery ©Maxar 2021).

Burned

Burned areas are those that were affected by prescribed fire in 2004 and natural fire in 2013 such that all or most spruce were killed and much of the shrub layer was removed. Different fire intensities and soils resulted in different successional stages at the time of observation in 2021. Generally, *burned* areas are dominated by *Betula* and *Salix* shrubs. They also tend to contain tree species, mostly *Picea* and *Populus* species, that are not yet structurally dominant (Figure 9).

Figure 9. Example of *burned* areas in mid-successional stages with dominant *Betula* and *Salix* shrubs intermixed with unburned *upland* dominated by *Picea mariana*.

Drainage/Shoreline

Drainage/shoreline occurs in areas that have topographic capacity to aggregate water but do not show persistent stream flow greater than 2 m width. At some times, such as during snow melt, drainages may contain ephemeral streams. In other cases, drainages may never show substantial surface flow, but they still aggregate water in the soils. In montane areas of the Alphabet Hills, drainages often support high abundance of *Alnus alnobetula* ssp. *fruticosa* and *Salix* species. In the surrounding lowlands, drainages often contain wetland sedge-dominated plant communities. Shorelines are included with drainage because of similarities in soil moisture regime and ephemeral water coverage during the growing season.

Figure 10. Drainages situated in upland (left) and lowland (right) show little to no persistent flowing surface water throughout the growing season but have high soil moisture from subsurface flow.

Floodplain

Floodplains are areas containing and surrounding rivers and large streams that flood at least periodically such that hydrologic erosion and deposition contribute to the disturbance regime. The organic soil layer ranges from thin or absent in the most commonly flooded zones to thick in zones that are infrequently and irregularly flooded. Exposed mineral soil is common within floodplains, but we have included such areas in the *barren* class. Similarly, although the floodplains contain river channels or streams, we have included such areas as the *water* class.

Figure 11. *Floodplain* along the West Fork of the Gulkana River, including an abandoned channel, vegetated floodplains, and floodplain barrens.

Riparian

Riparian areas are zones around and including streams where soil moisture regime is influenced by the stream for at least part of the growing season. The *riparian* corridor is usually narrowly restricted to the area adjacent to the stream (Figure 12). A primary difference between a *riparian* corridor and a *floodplain* is that the *riparian* corridor does not receive substantial deposition of materials from the stream flow. We mapped *riparian* corridors only where we observed streams at least 2 m across with visible water in the Maxar imagery composite that flowed into rivers or lakes. Streams that do not meet the mapping criteria are present in the Alphabet Hills study area but are not represented in the *surficial features* dataset.

Figure 12. A *riparian* corridor cuts through the center of the photograph. There is enough surface flow throughout the growing season to form a persistent stream, but sediment deposition is not a primary disturbance factor.

Water

Water is mapped where water persists as the reflectance surface without emergent vegetation throughout the growing season and as an approximate mid-point across seasonal changes in river and lake levels. The *water* class includes streams or rivers wider than 6 m. Because our map prioritizes terrestrial systems, waterbodies with high cover of floating aquatic vegetation were mapped as water.

Figure 13. Numerous lakes ranging widely in size are present in the Alphabet Hills study area. The floating aquatic plant *Nuphar polysepala* is abundant in the shown waterbody.

Upland/Lowland

The *upland/lowland* class is a merged class of uplands and lowlands, which typically intergrade without clear distinctions. Lowlands tend to be poorly drained and therefore wet while uplands tend to be well to moderately drained. Because of differences in hydrologic regimes and soils, upland and lowland vegetation types can often be distinguished floristically. For the purposes of delineating *existing vegetation types* related to USNVC alliances, we relied on floristic distinctions between upland and lowland types informed by the *foliar cover* maps. Thus, we did not need to map uplands and lowlands as separate classes. For example, *Picea glauca*-dominated vegetation types are common on moderately drained boreal uplands while *Picea mariana*-dominated vegetation types are common on poorly drained boreal lowlands (Figure 14). In addition to *Picea* species, the lowland vegetation types can often be distinguished by the presence of *Eriophorum vaginatum*, *Carex bigelowii*, *Sphagnum* mosses, and obligate wetland sedges.

Figure 14. The *upland/lowland* class includes upland (left) and lowland (right) vegetation types.

Aspen

The *aspen* class is an *existing vegetation type* rather than a *surficial feature*. We mapped *aspen* with the *surficial features* because we lacked a *foliar cover* map for *Populus tremuloides* from which to derive the *aspen / white spruce – aspen* type using a programmatic key. The *aspen* class is relatively rare in the study area, occurring on well-drained hillocks (Figure 15), lower montane outcrops, and south-facing bluffs. Because the class is rare, our *surficial features* and *existing vegetation type* map products relied on manual digitization of *aspen* communities.

Figure 15. *Aspen* is a vegetation class dominated or co-dominated by *Populus tremuloides* that occurs on relatively dry and well-drained sites, such as the tops of hillocks.

Appendix 3: Map Class Schema for Existing Vegetation Type

Per standards set by the Federal Geographic Data Committee (FGDC), map classification schemas for vegetation maps created by or for federal entities must relate to vegetation types in the U.S. National Vegetation Classification (USNVC). The map class schema for *existing vegetation type* is derived from USNVC (version 2022-05-01) and targets the alliance level (Table 12). In the current version, USNVC contains inconsistencies and errors for Alaska. We therefore modified the USNVC to incorporate alterations to the tree-dominated types of the boreal zone recommended by Flagstad et al. (2021). Additionally, we merged some alliances into map classes where alliance definitions resulted in poor separation or redundancy between types. The map class schema includes only the alliances that occur within the Alphabet Hills study area. Providing descriptions and field keys for the USNVC is beyond the scope of this study; such work, however, is a critical data need to aid consistent application and interpretation of USNVC in the future. Boreal alliances in USNVC version 2022-05-01 are unintuitive, frequently redundant, incomplete, and in need of major revision. In general, boreal alliances are too specific to provide an exhaustive and generalizable set of types. In the map classification schema, we have attempted to mitigate classification problems to a set of classes that are exhaustive for the study area, mutually exclusive, and aligned with divisions among existing alliances.

Alliances in Table 12 are labeled by source:

‡ Alliance from Flagstad et al. 2021

§ Alliance from USNVC version 2022-05-01

Table 12. Map class schema for *existing vegetation type* and correspondence to USNVC alliances (from USNVC version 2022-05-01 or Flagstad et al. 2021).

Map Vegetation Class	USNVC Alliances
barren	N/A
sparsely vegetated	western boreal *Dryas* – lichen rock vegetation§ western boreal mixed forb rock vegetation§ western boreal mixed lichen rock vegetation§
water	N/A
balsam poplar floodplain (white spruce)	*Populus balsamifera* – (*Picea glauca*) / *Alnus incana* ssp. *tenuifolia* / *Calamagrostis canadensis* – *Equisetum arvense* floodplain forest‡
white spruce floodplain	*Picea glauca* – *Populus balsamifera* / *Alnus viridis* ssp. *crispa* [not accepted] central floodplain forest§ *Betula papyrifera* [= *neoalaskana*] – *Picea* spp. central floodplain forest§
alder – willow floodplain	*Alnus viridis* ssp. *crispa* [not accepted] – *Alnus incana* ssp. *tenuifolia* / *Equisetum arvense* central mesic floodplain shrubland§

Map Vegetation Class	**USNVC Alliances**
black spruce, mesic	*Picea mariana* / *Vaccinium uliginosum* – *Betula glandulosa* / N–fixing feathermoss woodland[‡] *Picea mariana* / ericaceous dwarf shrub / feathermoss – lichen upland forest[‡]
black spruce, wet	Picea mariana / Vaccinium vitis–idaea – Rhododendron groenlandicum / Sphagnum wetland[‡] *Picea mariana* / *Vaccinium uliginosum* – *Rhododendron tomentosum* / *Eriophorum vaginatum* / *Sphagnum* wetland[‡]
white spruce – alder	*Picea glauca* / *Alnus alnobetula* / feathermoss upland forest[‡]
white spruce – birch shrub	*Picea glauca* / *Rhododendron tomentosum* – *Betula nana* woodland[‡]
white spruce – willow	observed but not described
mixed spruce (– Alaska birch)	*Picea glauca* – *Betula neoalaskana* – *Picea mariana* – (*Populus balsamifera*) / *Rosa acicularis* / *Calamagrostis canadensis* – *Equisetum arvense* upland woodland and forest[‡]
aspen / white spruce – aspen	*Populus tremuloides* / turf moss dry forest[‡] Populus tremuloides – (Picea glauca) / Arctostaphylos uva–ursi dry forest[‡]
birch	*Betula kenaica* / *Calamagrostis canadensis* upland forest[‡] *Betula neoalaskana* / *Rosa acicularis* / N–fixing feathermoss upland forest[‡] *Betula neoalaskana* / *Calamagrostis canadensis* woodland[‡]
alder – willow	*Alnus viridis* ssp. *crispa* [not accepted] – *Salix bebbiana* / *Calamagrostis canadensis* central mesic shrubland[§] *Alnus viridis ssp. crispa* [not accepted] central montane shrubland[§]
birch shrub – willow, mesic	*Betula nana* – *Salix pulchra* – *Ledum palustre* ssp. *decumbens* [not accepted] low shrubland[§] *Salix pulchra* / *Calamagrostis canadensis* low shrubland[§] *Betula nana* dry montane shrubland[§] *Betula nana* alpine shrubland[§] *Salix pulchra* alpine shrubland[§]
birch shrub – willow, wet	*Betula nana* poor fen[§] *Betula nana* – *Salix pulchra* / *Eriophorum vaginatum* wet shrubland[§] *Salix pulchra* / *Calamagrostis canadensis* wet shrubland[§]

Map Vegetation Class	USNVC Alliances
montane Dryas–ericaceous dwarf shrub	*Dryas octopetala* [not accepted] acidic alpine dwarf–shrubland§
boreal sedge meadow, wet	*Carex chordorrhiza – Carex aquatilis – Carex limosa* poor fen§ *Carex aquatilis* – mixed sedge alkaline fen§ *Carex aquatilis – Carex* spp. – *Eriophorum angustifolium* sedge meadow§
boreal montane herbaceous	*Carex bigelowii – Dryas integrifolia* alpine meadow§
boreal herbaceous	*Calamagrostis canadensis – Chamerion angustifolium* [not accepted] boreal mesic meadow§ *Calamagrostis canadensis* – mixed forb–graminoid meadow§ *Calamagrostis canadensis* western boreal wet meadow§

Appendix 4: Forage Species not included as Biomass Maps

For several reasons, we were not able to map *forage biomass* for all forage species that we observed in the Alphabet Hills study area. Table 13 provides a list of the species for which we did not map *forage biomass* and the reason that prevented us from doing so.

Table 13. Forage plant species that we observed in the Alphabet Hills study area but for which we did not produce maps of *forage biomass.*

Taxon	Non-zero Sites	Median Mass	Mean Mass	Reason
Betula cf. *occidentalis*	6	1	3.6	Low number of non-zero observations; low forage biomass where present.
Betula neoalaskana	3	1.2	1.1	Low number of non-zero observations; low forage biomass where present.
Betula kenaica	0	N/A	N/A	Observed on one plot; mature trees with no forage biomass within reach of moose.
Populus balsamifera	6	0.3	0.6	Low number of non-zero observations; low forage biomass where present.
Populus tremuloides	13	1.6	9.4	Low number of non-zero observations; low forage biomass where present (mostly mature trees with no forage biomass within reach of moose).
Salix alaxensis	5	0.9	0.9	Low number of non-zero observations; low forage biomass where present.
Salix arbusculoides	2	1.6	1.6	Low number of non-zero observations; low forage biomass where present.
Salix barclayi	14	1.1	9.4	Requires *foliar cover* map of *Salix barclayi* for further investigation; mapping may still be hampered by low number of non-zero observations and relatively low forage biomass where present.
Salix bebbiana	19	1.2	2	Requires *foliar cover* map of *Salix bebbiana* for further investigation; mapping may still be hampered by low number of non-zero observations and relatively low forage biomass where present.
Salix glauca	45	4.5	6.8	Requires *foliar cover* map of *Salix glauca* for further investigation; mapping may still be hampered by low number of non-zero observations and relatively low forage biomass where present.

Taxon	Non-zero Sites	Median Mass	Mean Mass	Reason
Salix richardsonii	19	2.8	8.2	Requires *foliar cover* map of *Salix richardsonii* for further investigation; mapping may still be hampered by low number of non-zero observations and relatively low forage biomass where present.
Salix scouleriana	9	1	1.6	Low number of non-zero observations; low forage biomass where present.