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Spectral reflectance and associated photograph of boreal forest understory formation in interior Alaska

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Abstract: The Arctic and boreal regions have been experiencing rapid warming in the 21st century. It is important to understand the dynamics of boreal forest on the continental scale under the climate and environmental changes. While the role of understory vegetation in boreal forest ecosystems on carbon and nutrient cycling cannot be ignored, they are still one of least understood components in boreal ecosystems. Spectroscopic measurements of vegetation are useful to identify species and their biochemical characteristics and to estimate the biophysical parameters such as understory leaf area index, above ground biomass. In this data paper, we present spectral reflectances of 44 typical understory formations and five 30-m long transects. The spectral reflectance covers the spectral region of visible, near infrared and shortwave infrared (350–2500 nm). For the transect measurements, we decided the length of transect at 30 m, similar to the scale of one pixel of a Landsat type satellite imagery. The photographs at all positions, where spectral reflectances were obtained, are included to understand the structure and status of each sample. The data set contains six dwarf shrubs (Bog bilberry (*Vaccinium uliginosum*), cranberry (*Vaccinium vitis-idea*), feltleaf willow (*Salix alaxensis*), young birch (*Betula neoalaskana*), young aspen (*Populus tremuloides*), and young black spruce (*Picea mariana*)), two herbaceous (cottongrass (*Eriophorum vaginatum*) and

marsh Labrador tea (*Ledum decumbens*)), three mosses (*Sphagnum* moss, splendid feather moss (*Hylocomium splendens*), and *polytrichum* moss (*Polytrichum commune*)), and reindeer lichen (*Cladonia rangiferina*). Spectral reflectances from several non-vegetative such as snow, litter, and soil are also included. This spectral and photographic data set can be used for understanding the spectral characteristics of understory formations, designing newly planned spectral observations, and developing and validating the remote sensing methodology of large-scale understory monitoring.

1. Background and Summary

The Arctic and boreal regions have been experiencing rapid warming in the 21st century[1]. It is important to understand the impact of climate and environmental changes on those regions at the continental scale[2,3]. While dominant tree species are often focused in the study of carbon and nutrient cycle in the boreal forest ecosystems[4], the characteristics of understory vegetation in carbon and nutrient cycling are less understood[5]. However, the growing number of evidences have shown the understory accounts for a large fraction of primary production and energy balance in boreal ecosystems, and their role must not be negligible[6].

Understory in boreal forests generally constitutes dwarf shrubs, herbaceous species, mosses, and lichens[7,8]. The abundance and spatial variability of understory species are diverse depending on the presence of permafrost, soil wetness, nutrient, and micro-topographical conditions. Wildfires also alter the composition and diversity of understory species[9,10]. Although there is a study of phenological pattern of understory[11], species-specific phenology of understory vegetation is not thoroughly investigated.

Spectroscopic measurements of vegetation are a useful tool to identify species and their biochemical characteristics and to estimate the biophysical parameters such as understory leaf area index, above ground biomass. The spectral measurements are made not only at the ground level but also by remote sensing from satellites and aircrafts. Several past studies have attempted to monitor the understory spectral reflectance from satellites to obtain the large-scale spatial variability of species and their temporal changes[12,13]. These satellite measurements often contain noises and errors due to cloud contamination, insufficient radiometric corrections, and uncertainties in retrieval algorithms. Ground-based understory measurements provide the validation datasets for remote sensing of understory reflectance. In northern European boreal forests, some existing studies have shown the measurements of seasonality of understory spectral reflectance along transects and within quadrats[14,15]. In Alaska, Kushida *et al.* (2004) [16] measured understory spectral reflectance at three locations with 30 by 30 m sampling plots to obtain the representative spectra of feather moss, sphagnum moss, and lichen. While there are a few existing studies regarding the understory spectra in boreal forests, the amount of data is quite limited to draw a comprehensive picture of the state and dynamics of boreal forest understory. The previous studies also provided limited spectral ranges (300-1000nm) or presented only limited understory species compositions.

In this data paper, we present spectral reflectances of 44 understory formations (UF) and five 30-m long transects (TR). The spectral reflectance covers the spectral region of visible, near infrared and shortwave infrared (350–2500 nm). The forest ecosystems of understory formations include mature black spruce forests, deciduous forests, and the recovery stage of black spruce forests after the wildfire in 2004. For the TR measurements, we set the transect length as 30 m that fits in one pixel of Landsat type satellite imagery. In the remote sensing and spectroscopic studies, pure spectral signatures of individual species may be desirable; however, in boreal forests, the majority of understory are covered with a mixture of shrubs, herbaceous species, mosses, and lichens. Thus, the spectra obtained in this study reflect the status of the understory formations that occur naturally in the environment. Furthermore, the visual information of understory formation aids to interpret the spectrum so that photographs of all positions, where spectral reflectances were obtained, were taken by a digital camera. Fig. 1 shows the geographical distribution of the sampling sites in interior Alaska. The understory formation spectra were obtained in the Poker Flat Research Range of the University of Alaska, Fairbanks (Fig. 1 UF001~UF044). Five transect measurements were also performed in various locations in Alaska (Fig. 1 TR001~TR005).

Table 1 shows the summary of dominant species of each UF record. At present, the UF spectral reflectance data are for six dwarf shrubs (Bog Bilberry (*Vaccinium uliginosum*), low bush cranberry (*Vaccinium vitis-idea*), feltleaf willow (*Salix alaxensis*), young birch (*Betula neoalaskana*), young aspen (*Populus tremuloides*), and young black spruce (*Picea mariana*)), two herbaceous (cottongrass (*Eriophorum vaginatum*) and marsh Labrador tea (*Ledum decumbens*)), three mosses (*Sphagnum* moss, splendid feather moss (*Hylocomium splendens*), and *polytrichum* moss (*Polytrichum commune*)), and reindeer lichen (*Cladonia rangiferina*). In UF data, several non-vegetative spectral reflectances such as snow, litter, and soil are also included. Table 2–6 show the location of five transects and the dominant species on the locations of spectral measurements. The dominant species of the understory formation along the transects were identified from the photographs that were concurrently taken with the spectral reflectance. The transect measurements except for TR003 were conducted at the black and white spruce understory. TR003 was conducted in the open shrub near the Denali National Park. The landscape of TR003 was fully covered with about 1 m-tall dense willows (Photographs are in the data file).

Figs 2 and 3 are the examples of the measured spectral reflectances and the associated photographs. The two moss dominant understory formations (Feather moss and Sphagnum moss) show a distinct feature of spectral shapes in the short-wave infrared (1500–2000nm): lower reflectivity of Sphagnum moss is seen in the short-wave infrared. This feature was also documented in Kushida *et al.* (2004)[16]. Another example in Fig. 3 shows spectra of Labrador tea and cowberry dominant understory formations. They show different spectral patterns in the near infrared (700–1000nm). This spectral and photographic data set can be used for understanding the spectral characteristics of understory formations, designing newly planned spectral observations, and developing and validating the remote sensing methodology of large-scale understory monitoring.

2. Location

The observation locations are indicated in the Fig. 1.

1. Measurement of understory formation:

   Poker Flat Research Range, University of Alaska, Fairbanks, 30 Mile Steese Hwy, Fairbanks, AK 99712, USA (65.12°N, 147.48°W, WGS-84), also see UnderstoryFormation-record.csv for exact locations of each measurement.

2. Transect measurements:

   There are five transects along the Alaskan highway and Dalton highway (Table 2).

Note that, to protect our monitoring plots, geo-locations are rounded at the second decimal. The exact geo-locations (WGS-84) may be provided depending upon the request.

3. Methods

1. Spectral reflectance and photograph of understory formations:

The spectral reflectances of 44 understory formations were obtained in the Poker Flat Research Range (PFRR) of the University of Alaska, Fairbanks in summer and early autumn seasons (July 14, 2013, September 8 to 9, 2014). In addition, understory spectra covered with snow were measured on March 25, 2015. These measurements were performed to obtain various growing stages (green matured plants, and senescence plants) of understory plants. The ASD FieldSpec 4 spectroradiometer (sampling range: 350 to 2500 nm, sampling interval: 1nm, spectral resolution: 3nm@700 nm, 8 nm@1400/2100 nm, the field of view of fiber probe: 25°) was used in these measurements. The spectral reflectances were calculated as a ratio of the reflected spectral radiance of the target understory and the white reference board (Spectralon, 99% reflectivity, Labsphere Inc.). The light sources were either sunlight or a light stand with two halogen light bulbs (130V, 500W x 2, w/ UV filter). The measurements under the sunlight were performed under completely diffuse radiation or clear sky under beam radiation. The measurements with a halogen light stand were conducted in a canopy surrounded by black curtains which intercept 99% of ambient lights (Fig. 4). The direction of halogen light beam was about 45 degrees. The FieldSpec 4 optical fiber probe was set at the nadir view (0° zenith angle). However, several measurements were conducted with oblique the angle up to 20° from the nadir. The reflectance data with beam and diffuse sky conditions were considered as bi-directional and hemispherical-directional reflectance factors, respectively. Each understory measurement was repeated three to four times. At the same time, digital photographs of each understory formation were taken. The details of the measured conditions for each sample were described in the record file “UnderstoryFormation-record.csv.”

2. Transect measurements:

The spatial variability of the understory spectral reflectance, which is a proxy of the abundance of understory species, was obtained by the transect method. The five transects were prepared in interior Alaska (see Fig. 1), and the length of each transect was 30 m. The spatial interval of the measurements was 2 or 3 m depending on the sites. The number of reflectance samples was 11 or 16 for each transect. The ASD FieldSpec 4 spectroradiometer (sampling range: 350 to 2500nm, sampling interval: 1nm, spectral resolution: 3nm@700nm, 8nm@1400/2100nm, the field of view of fiber probe: 25°) was used in these measurements. The spectral reflectances were calculated as a ratio of reflected spectral radiance of the target understory and the white reference board (Spectralon, 99% reflectivity, Labsphere Inc.). All measurements were conducted with a natural light source and most of the measurements were under the conditions with diffuse radiation. The reflectance factor was determined similarly to the measurement as the understory formation measurements. The details of the measured conditions for each sample were described in the record file “Transect-record.csv”. The digital photographs at each sampling point were taken. TR001 and TR002 transect also contain the images taken by spherical digital photography (RICHO Theta).

4. Data Record

Spectral reflectance and the photograph data are archived and published at National Institute of Polar Research Arctic Data Archive System (see Data Citation 1). Spectral reflectance and photograph of understory formations and transect measurements are stored in the directories named “UnderstoryFormation” and “Transect”, respectively. The sub-directory and the data stored as follows:

Subdirectory of understory formation samples

- UnderstoryFormation/UnderstoryFormation-record.csv

  Detail description of each record. One record contains 35 spectral reflectances of each understory formation sample. Record IDs are “UFxxx”, where xxx is the number of sample 001, 002…044.

- UnderstoryFormation/Spectra

Spectral reflectance data of each sample are in a CSV format. The filename is related with Record IDs such as UF001.csv, UF002.csv. UF044.csv. The first line of each record file is a header section. The following lines are the spectral reflectance data from 350 to 2500nm. Each record has 3 to 5 samplings and they are named as UFxxx-01 to UFxxx-05 (xxx = 001, 002 … 044).

Wavelength	UFxxx-01	UFxxx-02	UFxxx-03	UFxxx-04	UFxxx-05
350	0.051	0.110	0.053	0.067	0.076
351	0.068	0.098	0.052	0.067	0.106
…	…	…	…	…	…
2499	0.051	-0.012	0.039	0.061	0.015
2500	0.049	-0.020	0.048	0.074	0.011

- UnderstoryFormation/Figures

Figures of spectral reflectance (PDF format). The file names are associated with Record ID.

- UnderstoryFormation/Photograph

Photographs of each understory formation. The file names are associated with Record ID.

Subdirectory of transect measurements

- Transect/Transect-record.csv

Detail description of each record. One record contains 11 or 16 spectral reflectances of each transect. Record IDs are “TRxxx”, where xxx is the number of sample 001, 002…005.

- Transect/Spectra

Spectral reflectance data of each transect are in a CSV format. The filename is related with Record IDs of the transect such as TR001.csv, TR002.csv. TR005.csv. The first to line of each record file is a header section. Each record has 11 or 16 samplings and they are named with two digits distance identifier, TRxxx-00m to TRxxx-03m. The second line is the distance (m) from the beginning of transects. The third line is the sky condition flag. When the spectral reflectance was measured under diffuse radiation, flag = 0, and under the beam, flag = 1. The forth line is the dominant species identified from the photographs. The fifth and following lines are the spectral reflectance data.

Wavelength	TRxxx-00m	TRxxx-03m	…	TRxxx-030m
Distance(m)	0	3	…	30
Sky_flag(diffuse=0 or beam=1)	0	1	…	0
Dominant_species	Blueberry	Moss&lichen	…	Blueberry
350	0.051	-0.012	…	0.015
…	…	…	…	…
2499	0.051	-0.012	…	0.015
2500	0.049	-0.020	…	0.011

- Transect/Figures

  Figures of spectral reflectance (PDF format). The file names are associated with Record ID.

- Transect/Photograph

  Each sub-directory contains photographs of understory images of each point. The file names are associated with Record ID and the distance (m) from the starting point of the transect. The TR001 and TR002 transects also contains the images taken by digital spherical photography (RICHO Theta).

5. Technical Validation

For the spectral reflectance measurements for each species (from UF001 ~ UF044), the same species samples were measured three to five times repeatedly and the calculated spectral reflectances were plotted and visually checked. The outliers owing to the measurements that were unintentionally off the view of the target plants were removed from the final datasets.

Since the spruce forests are sparse and the light condition at the forest floors varies with space and time. In the current measurements, we chose the location where the light environments are stable around the target plant species in order to obtain the stable reflectance measurements. When the light conditions changed drastically in a short time, we waited for the measurements until the incoming light conditions were stabilized.

The outdoor measurements were conducted mostly under the diffuse sky conditions. However, there are several data that were taken under the clear sky (beam incoming radiation) conditions. All spectral reflectance data are provided with the skyflag (diffuse sky=0 and clear sky=1), and thus the users can judge the further criteria for the data application. In addition, the all spectral reflectance measurements are provided with photographs of the target locations. The field measurements of the spectral reflectance may not always be matched with the laboratory-based measurements due to the contamination of other species, light conditions, or the structure of the species. Users should check the photographs in order to understand the actual condition of the plant species that were measured in the field.

6. Competing Interests

No competing interests.

7. Figures

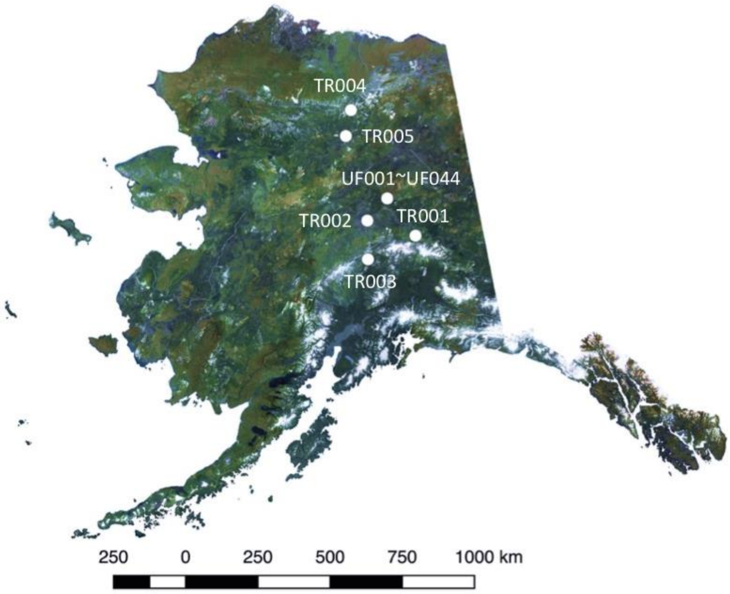

Fig. 1. Geographical distribution of the monitoring sites in Alaska.

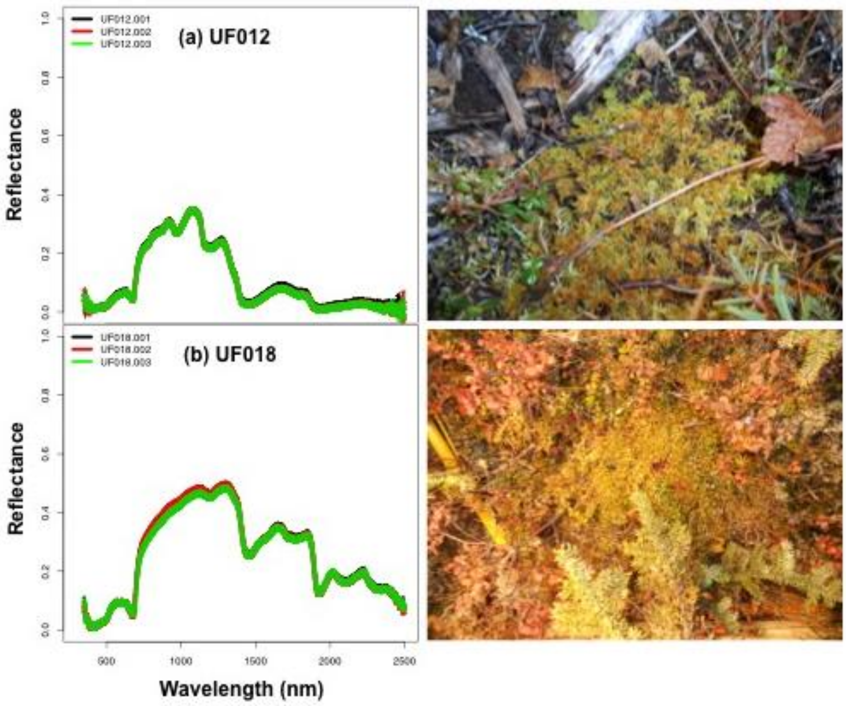

Fig. 2. Spectral reflectances and photographs for (a) Sphagnum moss and (b) Feather moss. Each measurement has three replications.

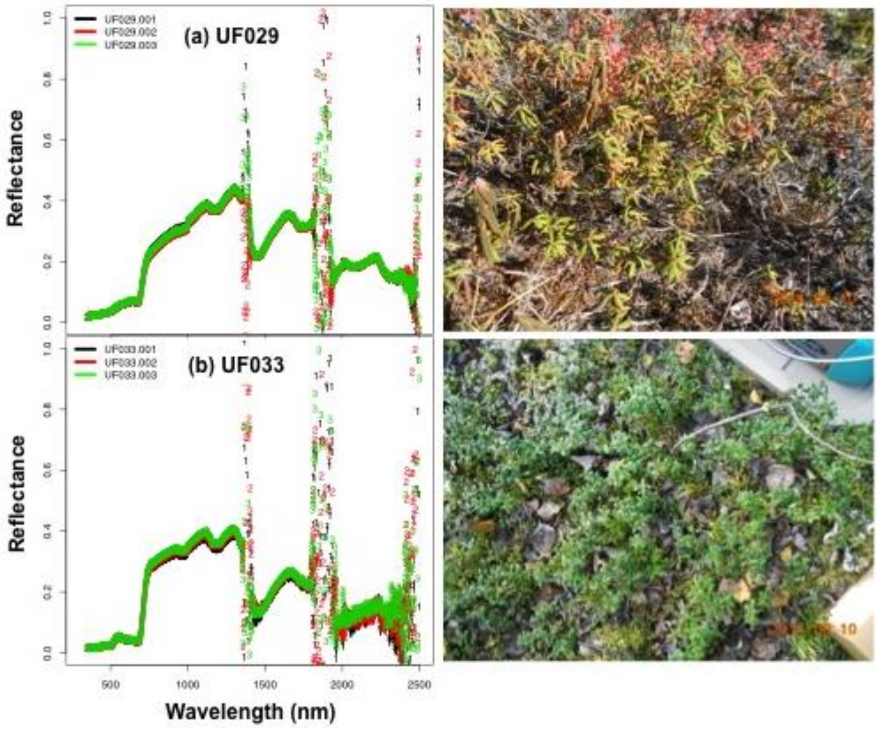

Fig. 3. Spectral reflectances and photographs for (a) Labrador tea and (b) cowberry. Each measurement has three replications.

Fig. 4. The outdoor canopy with black curtains for the spectral reflectance measurements.

8. Tables

Table 1. List of dominant species in each understory formation.

Record ID	Dominant species
UF001	Reindeer lichen (*Cladonia rangiferina*)
UF002	Marsh Labrador Tea (*Ledum decumbens*) on moss
UF003	Reindeer lichen (*Cladonia rangiferina*)
UF004	Cottongrass (*Eriophorum vaginatum*)
UF005	Cottongrass (*Eriophorum vaginatum*)
UF006	Bilberry (*Vaccinium uliginosum*) with marsh Labrador Tea on various moss
UF007	*Sphagnum* moss
UF008	Cottongrass (*Eriophorum vaginatum*)
UF009	Mix (cranberry, marsh Labrador tea, bog birch, *Sphagnum* moss)
UF010	Marsh Labrador tea (*Ledum decumbens*)
UF011	Dead leaves, litters and brown dry moss
UF012	*Sphagnum* moss
UF013	Reindeer Lichen (*Cladonia rangiferina*)
UF014	Cottongrass (*Eriophorum vaginatum*) with reindeer Lichen
UF015	Reindeer Lichen (*Eriophorum vaginatum*)
UF016	Reindeer Lichen (*Eriophorum vaginatum*)
UF017	Mix (bilberry, dwarf black spruce, Labrador Tea, Lichen)
UF018	Splendid feather moss (*Hylocomium splendens*)
UF019	Polytrichum moss (*Polytrichum commune*)
UF020	Young birch (*Betula neoalaskana*) on litters
UF021	Brown marsh Labrador Tea (*Ledum decumbens*) on green moss
UF022	Yellowish aspen (*Pupulus tremuloides*) on green moss
UF023	Feltleaf willow (*Salix alaxensis*) on green moss
UF024	Cottongrass (*Eriophorum vaginatum*)
UF025	Young black spruce (*Picea mariana*) and mixture of various species
UF026	Polytrichum moss (*Polytrichum commune*) with spore
UF027	Fallen bog of the 2004 fire
UF028	Dead cottongrass (*Eriophorum vaginatum*)
UF029	Marsh Labrador tea (*Ledum decumbens*)
UF030	Bilberry (reddish) (*Vaccinium uliginosum*)
UF031	Bare soil (dry)
UF032	Young black spruce (*Picea mariana*) on polytrichum moss
UF033	Cranberry (*Vaccinium vitis-idea*)
UF034	Cranberry (*Vaccinium vitis-idea*)
UF035	Marsh Labrador tea (*Ledum decumbens*)
UF036	Splendid feather moss (*Hylocomium splendens*)
UF037	Dead dry aspen leaves (*Pupulus tremuloides*)
UF038	Mixture of brown *Sphagnum* moss and bilberry (*Vaccinium uliginosum*)
UF039	Dead *Sphagnum* moss (almost soil)
UF040	Bilberry (reddish) (*Vaccinium uliginosum*)
UF041	Marsh Labrador tea (*Ledum decumbens*) and cranberry mixture on moss
UF042	Cottongrass (*Eriophorum vaginatum*)
UF043	Flat snow surface in sunlit
UF044	Flat snow surface in shaded

Table 2. Dominant species and sky conditions in the transect of Open black spruce forest near the town of Delta-Junction (63.86°N145.74°W) (TR001).

Transect	Sky_flag (diffuse=0 or beam=1)	Dominant_species
TR001-00m	0	Bilberry&Polytrichum juniperinum
TR001-03m	0	Moss&lichen
TR001-06m	0	Bilberry&litter
TR001-09m	0	Moss
TR001-12m	0	black spruce&bilberry&moss
TR001-15m	0	Bilberry
TR001-18m	0	Labrador tea&moss
TR001-21m	0	Litter
TR001-24m	0	Moss
TR001-27m	0	Bilberry
TR001-30m	0	Bilberry&moss

Table 3. Dominant species and sky conditions in the transect of Mature black spruce forest near the Nenana Municipal Airport (64.48°N, 149.08°W) (TR002).

Transect	Sky_flag (diffuse=0 or beam=1)	Dominant_species
TR002-00m	0	Labrador tea (mixture of grasses)
TR002-03m	0	Bilberry on moss
TR002-06m	0	Labrador tea on purple moss
TR002-09m	0	Labrador tea&Polytrichum juniperinum&cranberry
TR002-12m	0	Cranberry&bilberry&Labrador tea&Polytrichum juniperinum
TR002-15m	0	Labrador tea&moss
TR002-18m	0	Labrador tea&moss
TR002-21m	0	Labrador tea&moss
TR002-24m	0	Labrador tea&moss
TR002-27m	0	Labrador tea&Polytrichum juniperinum&cranberry
TR002-30m	0	Cranberry&moss

Table 4. Dominant species and sky conditions in the transect of Open shrub near the Denali National Park (63.27°N, 149.24°W) (TR003).

Transect	Sky_flag (diffuse=0 or beam=1)	Dominant_species
TR003-00m	0	Willow&bilberry
TR003-03m	0	Willow
TR003-06m	0	Willow on Polytrichum juniperinum
TR003-09m	0	Willow
TR003-12m	0	Willow
TR003-15m	0	Willow
TR003-18m	0	Willow
TR003-21m	0	Willow
TR003-24m	0	Willow
TR003-27m	0	Aspen
TR003-30m	0	NA

Table 5. Dominant species and sky conditions in the transect of White spruce forest north of Wismann (67.99°N, 149.76°W) (63.27°N, 149.24°W) (TR004).

Transect	Sky_flag (diffuse=0 or beam=1)	Dominant_species
TR004-00m	0	Bilberry&Polytrichum juniperinum
TR004-02m	0	Bilberry
TR004-04m	0	Dead grass&brown moss
TR004-06m	0	Bilberry&Polytrichum juniperinum
TR004-08m	0	Moss&Polytrichum juniperinum&willow
TR004-10m	0	Polytrichum juniperinum&moss&cotton grass
TR004-12m	0	Bilberry on moss
TR004-14m	0	Bilberry on moss
TR004-16m	0	Moss
TR004-18m	0	Bilberry on moss
TR004-20m	0	Polytrichum juniperinum&moss
TR004-22m	0	Bilberry on moss
TR004-24m	0	Polytrichum juniperinum&moss
TR004-26m	0	Polytrichum juniperinum&moss
TR004-28m	0	Lichen
TR004-30m	0	Bilberry&moss

Table 6. Dominant species and sky conditions in the transect of Black spruce forest south of Coldfoot (67.18°N, 150.30°W) (TR005).

Transect	Sky_flag (diffuse=0 or beam=1)	Dominant_species
TR005-00m	0	Moss
TR005-02m	0	Moss
TR005-04m	1	Lichen
TR005-06m	1	Moss
TR005-08m	1	Moss
TR005-10m	1	Lichen
TR005-12m	1	Labrador tea on lichen
TR005-14m	1	Cranberry
TR005-16m	0	Labrador tea on moss
TR005-18m	1	Moss
TR005-20m	0	Cranberry and lichen
TR005-22m	0	Labrador tea & cranberry & cotton grass
TR005-24m	0	Labrador tea & cranberry & dead cotton grass
TR005-26m	0	Labrador tea on moss
TR005-28m	0	Lichen and moss
TR005-30m	1	Lichen and moss

Author contributions

HK, RS, WY designed the measurements protocol and all members contributed to performed the spectral measurements and the preparation to the draft.

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Data Citations

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