Spectral Characteristics of the Arctic Vegetation in Adventdalen, Svalbard

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1. Introduction

- Remote sensing has been widely used in understanding the Arctic ecosystem.
- Spectral information, a proxy for understanding the characteristics of the ground target, can support the quantitative analysis of remote sensing. spectral library, serves as reference data in remote sensing analyses, is a database of digital reflectance spectra from ground truth data. spectral library plays an important role in identifying the targets and quantifying their abundance.
- Previous studies have addressed the Arctic ecosystem using remote sensing data [1, 2]. However, spectral information was limited, and similar vegetation structures cause poor spectral discriminability.
- To address these limitations, this study has two research purposes:

  (1) Development of a spectral library for six dominant species in Adventdalen, Svalbard: *Dryas octopetala, Eriophorum scheuchzeri* ssp. *arcticum, Equisetum sp.*, *Bistorta vivipara, Cassiope tetragona, and Salix polaris*

  (2) Investigation of an effective strategy for identifying the Arctic plant species from remote sensing imagery

2. Method

- Study area : Arctic tundra of Adventdalen, Svalbard
- Hyperspectral images were acquired using a hyperspectral camera Specim IQ across the 400 to 1000 nm wavelength range at a spectral resolution of approximately 3 nm.
- The hyperspectral image contained 204 bands. Reflectance values were converted using a white calibration target (Spectralon). However, the 900 to 1000 nm wavelength range was removed as noisy data.
- The spectral similarity, comparing the spectral discriminability between two spectra, was measured using six measures: Spectral Distance Similarity (SDS), Spectral Angle Mapper (SAM), Spectral Information Divergence (SID), Spectral Correlation Angle (SCA), SIDxSAM-sin, and SCAxSAM-sin (Table 1) [3].
- To evaluate the performance of the measures, Probability of Spectral Discriminability (PSD) was used as an objective statistical criterion [3].
- The present research proposed two approaches for the effective classification of Arctic vegetation to overcome the poor spectral discriminability of the Arctic plant species:
- (i) First derivative was applied to the original hyperspectral reflectance data to effectively classify the Arctic plants [4].
- (ii) Optimal wavelength and ratio value, distinguishing a species from other species in remote sensing data, were determined.

Table 1. List of spectral similarity measures

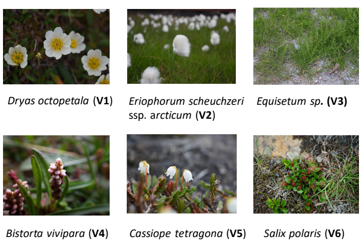
Method	Mathematical function
SDS	$SDS = \frac{\sqrt{\sum_{i=1}^{n}(x_i - y_i)}}{\sqrt{n}}$
SAM	$SAM = cos^{-1}\frac{\sqrt{\sum_{i=1}^{n}(x_i - yi)}}{\sqrt{\sum_{i=1}^{n} x_i^2}\sqrt{\sum_{i=1}^{n} y_i^2}}$
SID	$p_i = x_i / \sum_{i=1}^{n} x_i$, $q_i = y_i / \sum_{i=1}^{n} y_i$ $\quad SID = \sum_{i=1}^{n} p_i \log\frac{p_i}{q_i} + \sum_{i=1}^{n} q_i \log\frac{q_i}{p_i}$
SCA	$r_{x_i, y_i} = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{\sqrt{n\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2}\sqrt{n\sum_{i=1}^{n} y_i^2 - (\sum_{i=1}^{n} y_i)^2}}$ $\quad SCA = cos^{-1}(\frac{r_{x_i, y_i} + 1}{2})$
SIDxSAM-sin	Hybrid Method : SID x $sin(SAM)$
SCAxSAM-sin	Hybrid Method : SCA x $sin(SAM)$
$x = (x_1, x_2, \ldots x_n)^T$ $y = (y_1, y_2, \ldots y_n)^T$	n: number of band

3. Result

3.1. Spectral Library

- The spectral library of six Arctic plant species was developed using Region of Interest (ROI) associated with each plant species in optical images using ENVI software (Figure 1).
- All ROIs consisted of 1,000 pixels except for *Bistorta vivipara* (300 pixels) due to a lack of relevant pixels.

Six dominant species



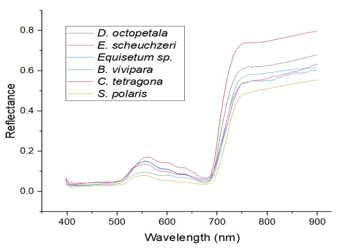


Figure 1. Spectral library of six Arctic plant species

3.2. Spectral Similarity Measures

- The low values of spectral similarity measure between two spectra indicated poor discriminability in Table 2.
- PSDs were compared according to the spectral similarity measures and species in Table 3.
- *S. polaris* (**V6**) showed relatively high overall PSDs compared to other species in Figure 2.
- SDS was most effective measure for identifying *C. tetragona* (**V5**) from the hyperspectral data of Arctic plants (Figure 2).
- However, the spectral discriminability of Arctic plant species was not significant for classification.

Table 2. Values of spectral similarity measure between two spectra of six plant species

	SDS	SAM	SID	SCA	SIDxSAM-sin	SIDxSCA-sin
V1-V2	0.045	0.055	0.011	0.054	0.001	0.001
V1-V3	0.045	0.036	0.006	0.030	0.000	0.000
V1-V4	0.037	0.057	0.013	0.056	0.001	0.001
V1-V5	0.077	0.025	0.002	0.024	0.000	0.000
V1-V6	0.084	0.084	0.021	0.072	0.002	0.001
V2-V3	0.012	0.033	0.003	0.034	0.000	0.000
V2-V4	0.021	0.054	0.011	0.045	0.001	0.000
V2-V5	0.119	0.068	0.010	0.071	0.001	0.001
V2-V6	0.045	0.070	0.025	0.034	0.002	0.001
V3-V4	0.026	0.065	0.017	0.056	0.001	0.001
V3-V5	0.121	0.049	0.006	0.050	0.000	0.000
V3-V6	0.046	0.088	0.031	0.060	0.003	0.002
V4-V5	0.111	0.068	0.014	0.065	0.001	0.001
V4-V6	0.050	0.042	0.007	0.030	0.000	0.000
V5-V6	0.159	0.100	0.028	0.085	0.003	0.002

Table 3. Probability of Spectral Discrimination produced by the measures

	SDS	SAM	SID	SCA	SIDxSAM-sin	SIDxSCA-sin
V1	0.289	0.288	0.258	0.308	0.229	0.257
V2	0.242	0.312	0.290	0.311	0.252	0.232
V3	0.250	0.303	0.312	0.301	0.308	0.292
V4	0.245	0.320	0.303	0.329	0.252	0.279
V5	0.589	0.347	0.294	0.384	0.326	0.366
V6	0.385	0.430	0.542	0.367	0.633	0.573
Entropy	2.073	2.179	2.125	2.189	2.050	2.091

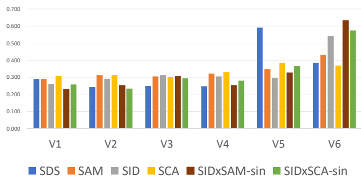


Figure 2. Probability of Spectral Discrimination in the bar chart

3.3. Derivative Analysis

- Compared to the original spectrum, spectral discriminability of the first derivative-spectrum (Figure 3) increased in SAM measure (Figure. 4).
- This result indicates that derivative analysis is effective in improving the spectral discriminability and can contribute to the Arctic plant species classification.

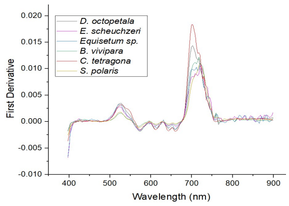


Figure 3. Derivative-spectral library of six Arctic plant species

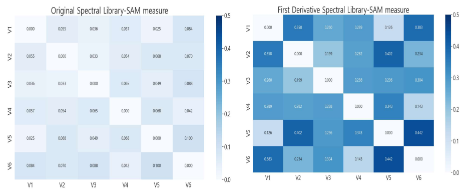


Figure 4. Heat-map comparison between original spectrum and derivative spectrum in SAM measure

3.4. Vegetation Index/Simple Ratio

- All species were evaluated using vegetation indices listed in Table 4 [5].
- Index values according to species and indices were listed in Table 5, highlighting the most effective values.
- *D. octopetala, E. scheuchzeri* ssp. *arcticum, Equisetum sp.* and *C. tetragona* were separated from other species using the optimal index values, but *B. vivipara and S. polaris* were difficult to identify.

Table 4. Vegetation Indices using in the study

Index	Name	Mathematical function
Reverse-RGR	Reverse-Red Green Ratio	$\frac{(R500 - R599)}{(R600 - R699)}$
TVI	Triangular vegetation index	$0.5 * (120 * (R750 - R550) - 200 * (R670 - R550))$
mNDVI705	Modified normalized difference vegetation index 705	$\frac{R750 - R705}{(R750 + R705 - 2R445)}$

Table 5. Optimal indices of Arctic plant species

	557nm/684nm	684nm/774nm	Reverse RGR	TVI	mNDVI705
Dryas octopetala	3.016	0.081	1.004	38.067	0.418
Eriophorum scheuchzeri	2.016	0.122	0.891	31.751	0.515
Equisetum sp	2.485	0.108	1.185	32.701	0.461
Bistorta vivipara	1.725	0.095	0.581	32.726	0.549
Cassiope tetragona	2.305	0.099	0.913	44.034	0.382
Salix polaris	2.036	0.079	0.615	28.61	0.597

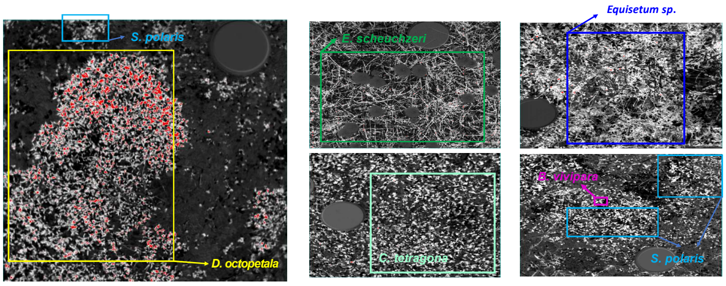


Figure 5. Index (557nm/684nm > 2.9) application in the hyperspectral images

4. Summary

- We developed a spectral library of six dominant plant species in the Adventdalen, Svalbard.
- Our result presented the optimal vegetation indices and derivative analysis as strategies for identifying each species from remote sensing imagery.
- The proposed approaches can provide detailed vegetation maps using remote sensing imagery and improve understanding of the Arctic ecosystem.

Reference

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