Mapping Capability of Hyperspectral Information to Identify Dominant Arctic Plant Species

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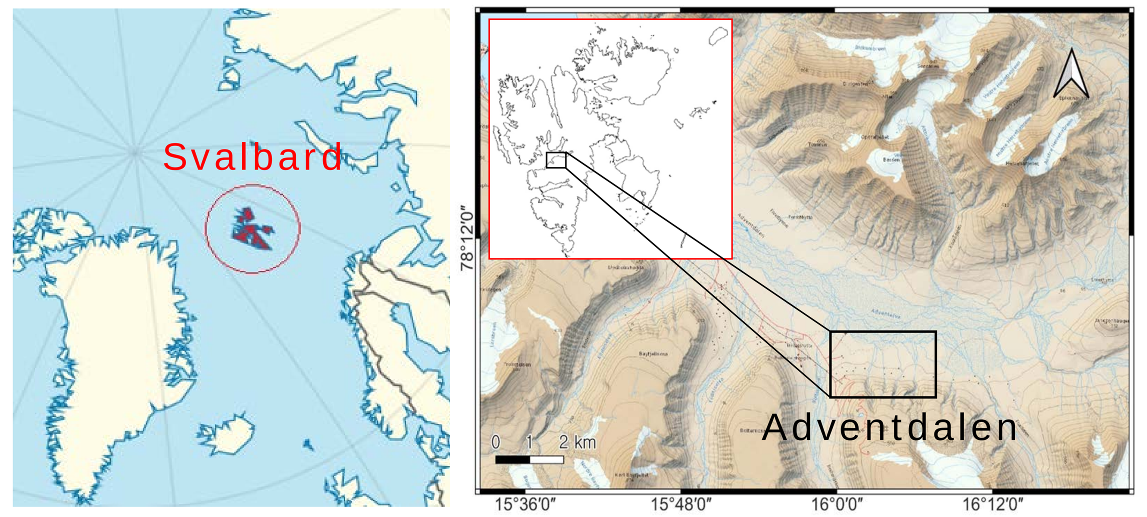
Introduction

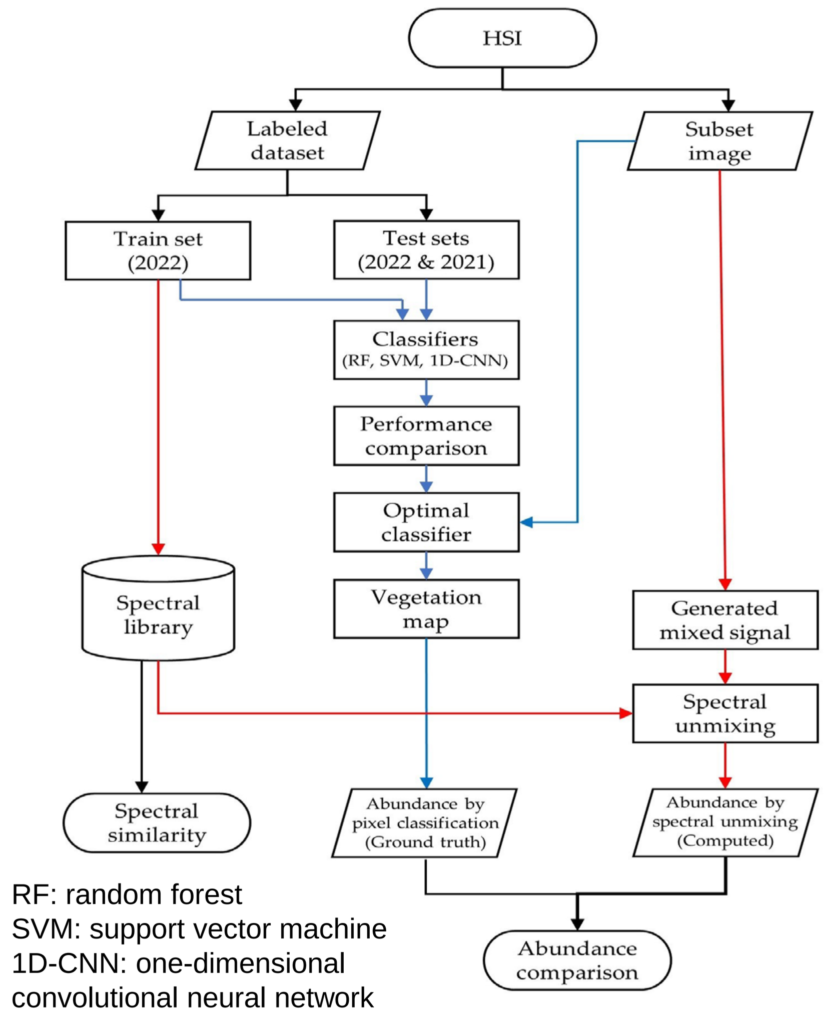
- Hyperspectral remote sensing is a useful tool for monitoring and understanding the rapid changes in the distribution and composition Arctic vegetation in response to climate change.
- However, hyperspectral information for monitoring is insufficient because of the challenge in acquiring data from the Arctic region.
- In addition, mixed pixels commonly formed in large-scale remote sensing images present an obstacle in accurately mapping Arctic vegetation.
- To address these limitations, this study included two research purposes:
  - (1) to develop a spectral library of dominant Arctic plants using a ground-based hyperspectral imagery
  - (2) to simulate the mapping potential of the spectral library in large-scale remote sensing data using spectral unmixing to address the mixed pixel issue

Materials and Methods



Study area and data acquisition

- Adventdalen, Svalbard, Norway (78˚09'55'' N and 16˚00'42'' E)
- Hyperspectral images were captured using a ground-based hyperspectral camera, covering the spectral range of 400 to 1000 nm with a spectral resolution of 3 nm during the Arctic summer seasons of 2021 and 2022.

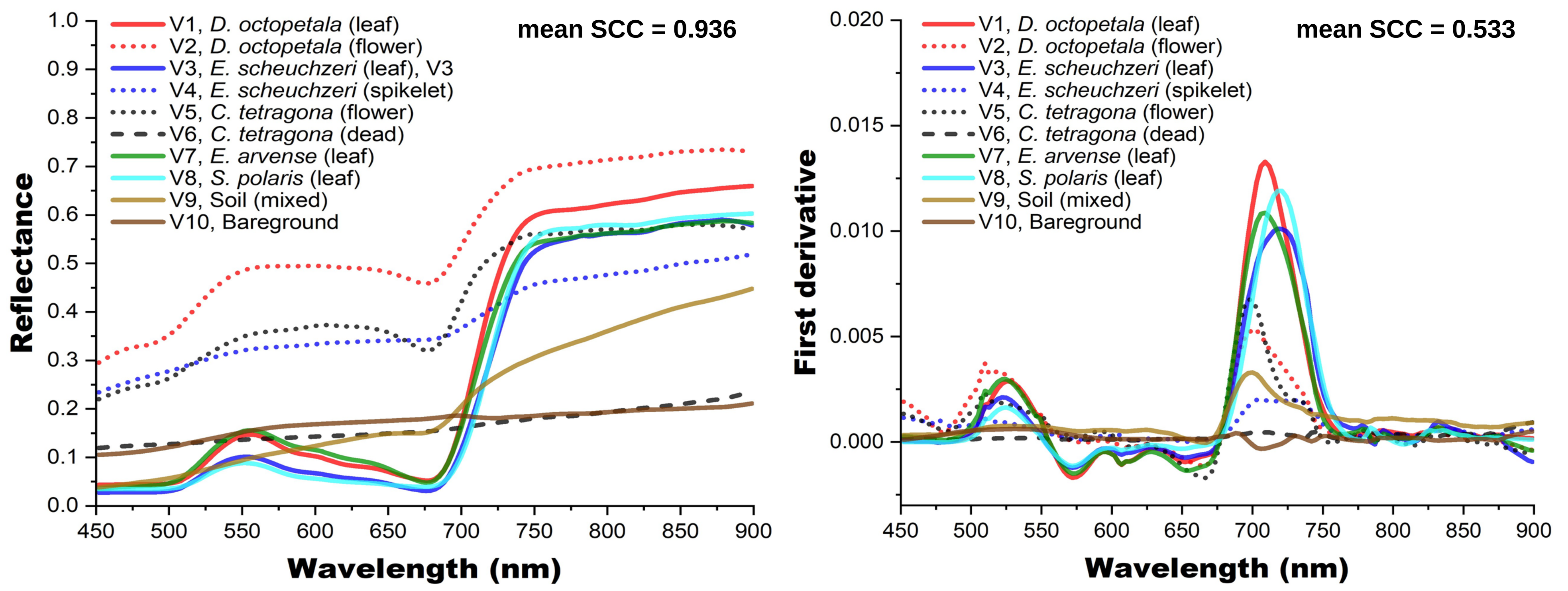


RF: random forest
SVM: support vector machine
1D-CNN: one-dimensional convolutional neural network

Research flow

- A spectral library was developed using the mean spectra per class of the labeled dataset.
- Spectral correlation coefficient (SCC), quantifying the degree of correlation between two spectra, was used to evaluate spectral similarity.
- A subset image was created by selecting a size of 100 × 100 pixels from the hyperspectral images and used to generate a mixed signal by averaging its pixel signals.
- Class-specific abundance was estimated from the mixed signals using spectral unmixing, with the spectral library serving as a reference (i.e., endmembers)
- The performances of three machine learning-based classifiers were compared to determine the optimal classifier for predicting the ground truth.
- The first derivative technique was involved in the experiment, aiming to increase spectral separability.

Spectral Library

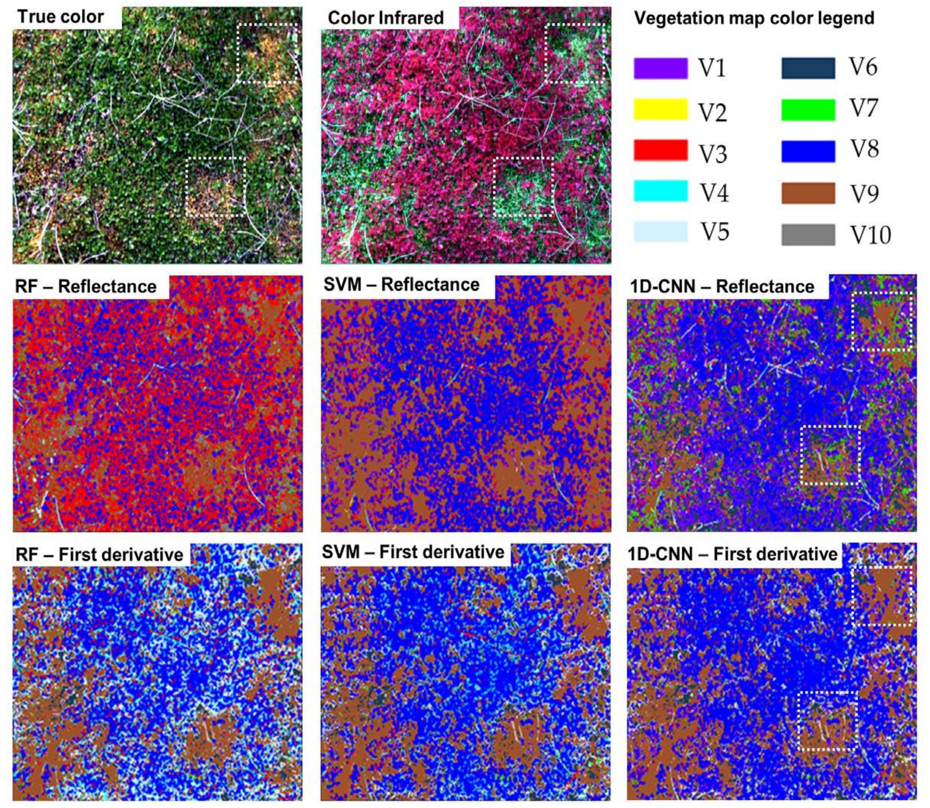


- Spectral patterns of the Arctic vegetation classes were visually distinguishable in the first derivative spectral library.
- When compared to the reflectance spectral library, the application of the first derivative resulted in a decrease in the mean SCC, indicating an increase in spectral similarity within spectral library.

Comparison of classification performances

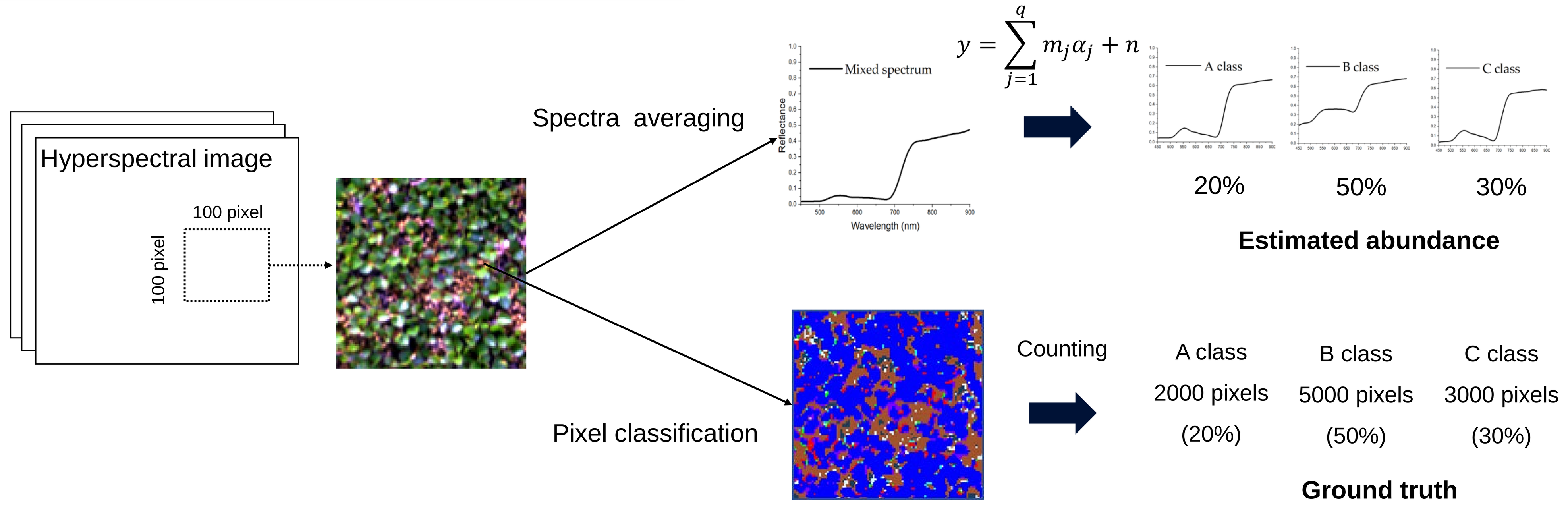
	Test set (2022) Reflectance			Test set (2021) Reflectance		
Classifier	RF	SVM	1D-CNN	RF	SVM	1D-CNN
Overall accuracy	0.915	0.964	0.972	0.735	0.890	0.928
Kappa coefficient	0.906	0.960	0.969	0.706	0.877	0.920

	Test set (2022) First derivative			Test set (2021) First derivative		
Classifier	RF	SVM	1D-CNN	RF	SVM	1D-CNN
Overall accuracy	0.966	0.988	**0.989**	0.906	0.875	**0.935**
Kappa coefficient	0.962	0.986	**0.988**	0.896	0.861	**0.928**



- The 1D-CNN classifier combined with the first derivative technique demonstrated most stable performance and achieved the highest statistical accuracy for two different test sets (highlighted in bold).
- In the qualitative evaluation, the 1D-CNN classifier applied with the first derivative produced most accurate vegetation map, showing better visual agreement with true color and color infrared images. Therefore, this classification method was used to estimate the ground truth from the subset images.

Spectral Unmixing



Dataset	Fractional abundance (Average)	Class										
		V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	Total
Subset images (2022)	Ground truth	0.08	0.02	0.08	0.07	0.07	0.23	0.05	0.11	0.22	0.07	1.00
	α_R	0.01	0.00	0.25	0.00	0.00	0.58	0.02	0.02	0.11	0.02	1.00
	$\alpha_{R,FD}$	0.09	0.01	0.08	0.00	0.02	0.41	0.02	0.10	0.21	0.06	1.00
Subset images (2021)	Ground truth	0.12	0.01	0.07	0.05	0.07	0.20	0.05	0.12	0.27	0.04	1.00
	α_R	0.01	0.00	0.25	0.00	0.00	0.58	0.02	0.02	0.11	0.02	1.00
	$\alpha_{R,FD}$	0.13	0.00	0.01	0.01	0.02	0.32	0.01	0.14	0.32	0.04	1.00

➢ $\boldsymbol{\alpha_R}$ and $\boldsymbol{\alpha_{R,FD}}$: Fractional abundance of a simulated mixed signal estimated using spectral library with reflectance and the first derivative of the reflectance, respectively.

- The $\boldsymbol{\alpha_{R,FD}}$ demonstrated a good match with the ground truth, whereas $\boldsymbol{\alpha_R}$ showed notable inconsistencies.
- In particular, $\boldsymbol{\alpha_{R,FD}}$ of leaf-based classes (V1, V3, V8 and V9) exhibited a significant agreement with the ground truth. This aligns with the increased spectral separability within first derivative spectral library.
- However, discrepancies were observed in the estimation of flower and spikelet classes (V2, V4 and V5). These classes comprise various structure with significantly different spectral characteristics, such as petals, sepals, and spikelets, leading to high intraspecies spectral variability.

Conclusion

- The spectral library for Arctic plants was developed and used to understand spectral characteristics of dominant plant species in Adventdalen.
- The application of first derivative significantly improved spectral separability and classification performances, highlighting its usefulness for accurately mapping Arctic vegetation.
- The spectral library with first derivative of reflectance demonstrated a high potential for estimating the distribution of Arctic vegetation from mixed signals.
- This study can be served as a fundamental research in mapping Arctic plants, playing a crucial role in detecting and understanding the changes in Arctic vegetation caused by climate change.

This work was supported by Korea Polar Research Institute (KOPRI) granted by the Ministry of Ocean and Fisheries (KOPRI PE22450).