Advances in Spectral Unmixing-based Hyperspectral Analysis for Arctic Plant Species Monitoring: Developing a Spectral Library

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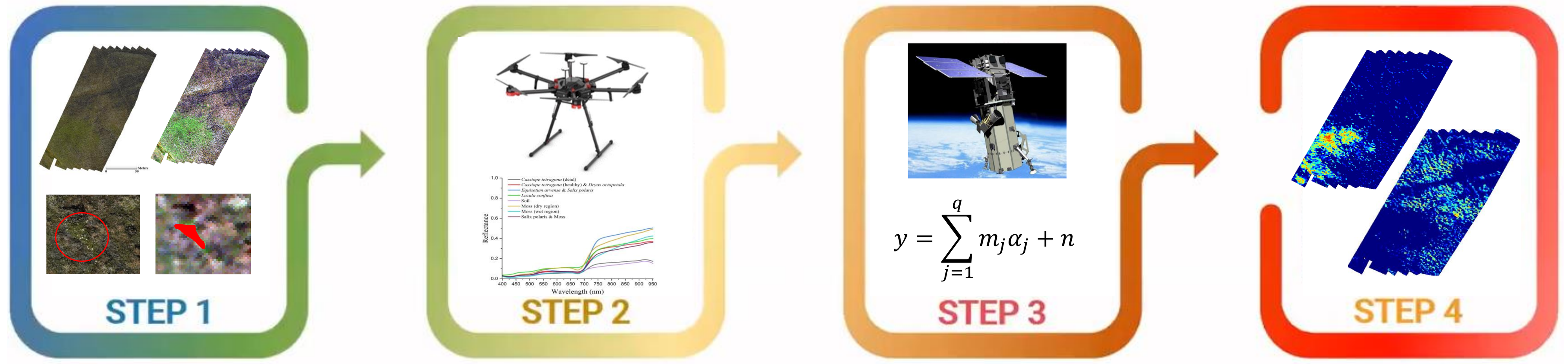
Summary



Data acquisition & Data labeling | UAV-based Spectral library | Unmixing satellite pixels | Class-specific abundance map

Introduction

- Remote sensing serves as an invaluable tool for monitoring the rapid changes in the distribution and composition of Arctic vegetation in response to climate change.
- However, mapping Arctic plant species remains challenging due to the difficulty in data acquisition from the Arctic region and the mixed pixel issue, which represents a mixture of more than one plant species caused by low spatial resolution in large-scale remote sensing imagery.
- To address these limitations, this study aims to achieve two main objectives: (1) collecting hyperspectral information for Arctic plant species and developing a spectral library using an unmanned aerial vehicle (UAV), and (2) estimating class-specific abundances from a WorldView-3 image using the UAV-based spectral library and the spectral unmixing solution.

Data acquisition

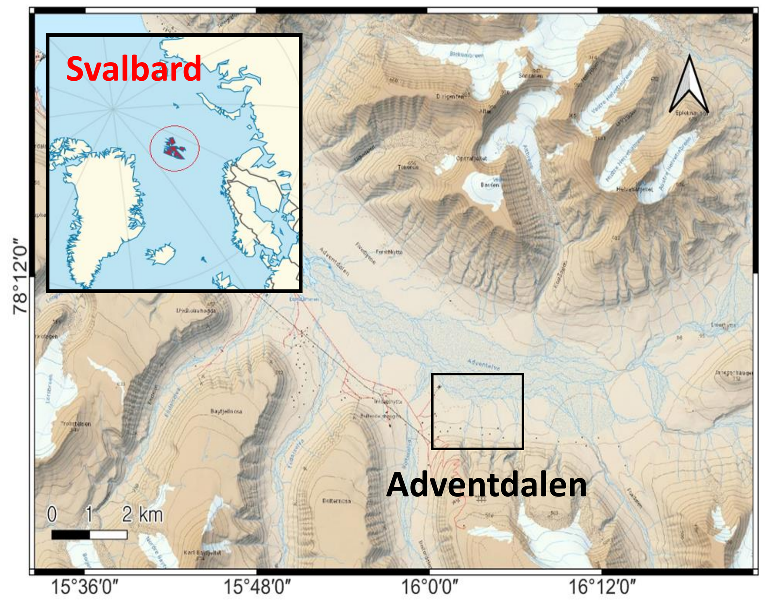
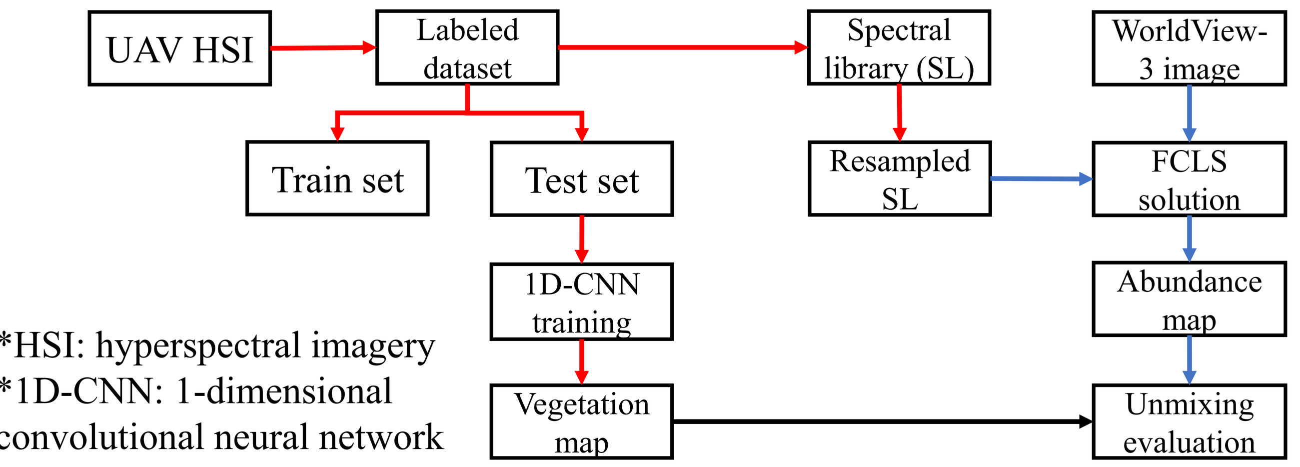


Figure 1. The study area located in Adventdalen, Svalbard, Norway (78˚09'55" N and 16˚00'42" E).

Table 1. A description of the UAV hyperspectral image and the WorldView-3 image used in the study

	UAV hyperspectral (DJI Matrice 600 Pro)	Worldview-3 multispectral
Spectral resolution	VNIR (400 – 1000 nm)	VNIR (400 – 1000 nm)
Spectral bands	137 bands (after binning)	8 bands
Spatial resolution	4 cm	1.24 m
Date of acquisition	2022-07-07	2021-08-08
Reflectance Normalization	using an empirical line method with three calibration targets (5%, 50% and 95% of gray scale steps)	using the radiometric calibration tool and the FLAASH module within the ENVI 5.6.1 software

Methods and Materials



UAV hyperspectral-based spectral library and vegetation map

Spectral unmixing using a WorldView-3 image

*HSI: hyperspectral imagery
*1D-CNN: 1-dimensional convolutional neural network

*FCLS: fully constraint least squares

$$M = \sum_{j=1}^{K} a_j E_j$$

M = mixed spectrum
E_j = j^{th} class spectrum
a_j = the fractional abundance of E_j

Two constraints
- $\sum_{j=1}^{M} a_j = 1$ (Sum-to-one)
- $0 < a_j$ (Non-negative)

Results

1) UAV-based spectral library

Table 2. Class description investigated in the study

Class ID	Class name
V1	*Cassiope tetragona* (dead)
V2	*Cassiope tetragona* (healthy) & *Dyras octopetala*
V3	*Equisetum arvense* & *Salix Polaris*
V4	*Luzula confusa*
V5	Soil
V6	Moss (dry region)
V7	Moss (wet region)
V8	*Salix polaris* & moss

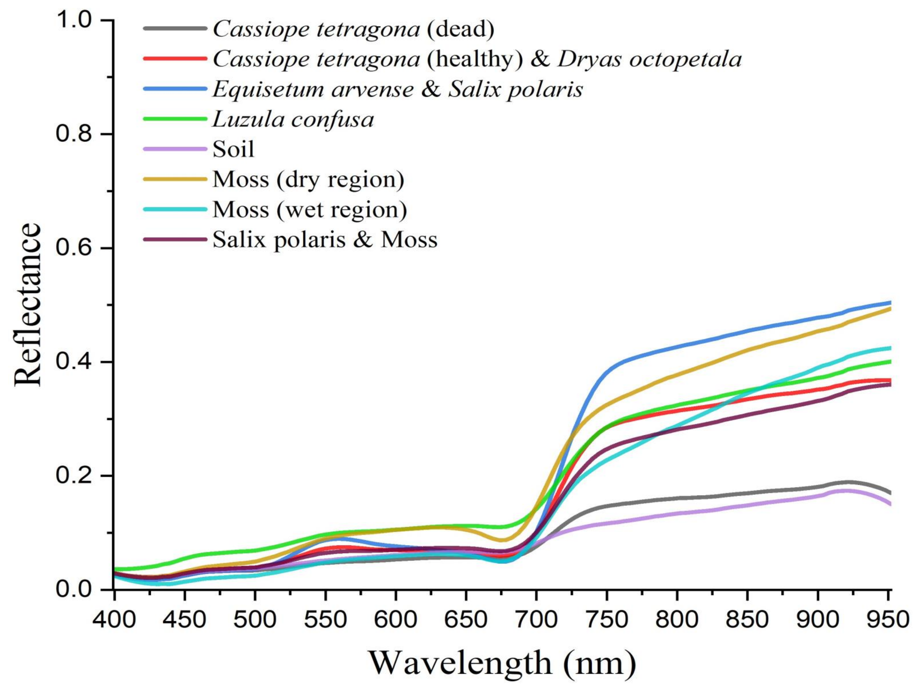


Figure 2. UAV-based spectral library for Arctic vegetation

2) UAV vegetation map for the validation purpose

Table 3. Statistical accuracy of UAV hyperspectral image classification using the 1D-CNN classifier

ID	1D-CNN Classifier		
	Overall accuracy: 0.980		
	Precision	Recall	F1-score
V1	0.969	1.000	0.984
V2	0.963	0.924	0.943
V3	0.977	1.000	0.988
V4	0.996	0.996	0.996
V5	1.000	0.992	0.996
V6	1.000	0.992	0.996
V7	0.994	0.994	0.994
V8	0.944	0.944	0.944

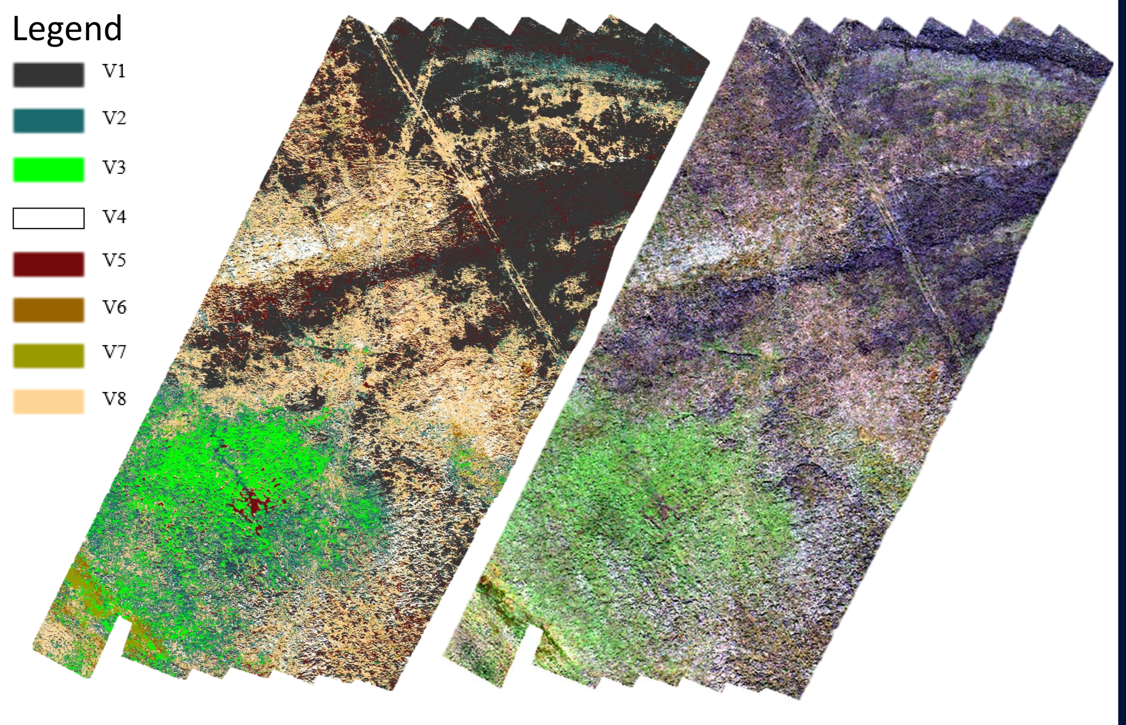


Figure 3. Image classification result. The UAV vegetation map classified using 1D-CNN (Left). UAV hyperspectral true color image (Right)

3) Statistical evaluation of spectral unmixing results

Table 4. Comparison of classification results for a UAV hyperspectral region (30 x 30 pixels) and spectral unmixing results for a WorldView-3 single pixel. The validation of spectral unmixing was performed using a total of eight regions, and their average values are displayed in the table.

Fractional Abundance (Average)	V1	V2	V3	V4	V5	V6	V7	V8	Total
Vegetation map (Ground truth)	0.26	0.12	0.15	0.09	0.02	0.04	0.14	0.19	1.00
Spectral unmixing (Worldview-3)	0.44	0.13	0.13	0.05	0.01	0.00	0.13	0.11	1.00

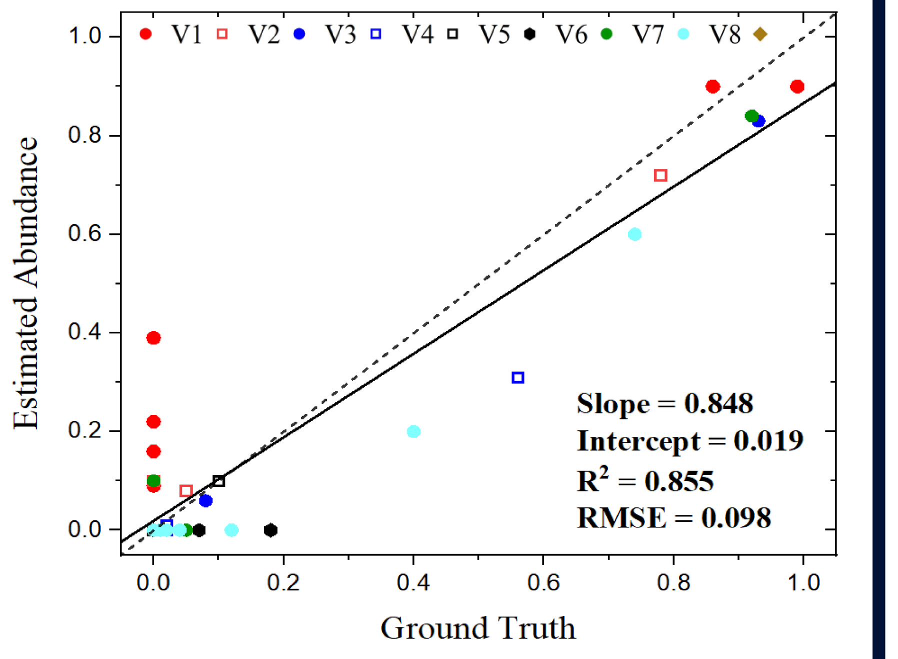


Figure 4. Statistical evaluation using coefficient of determination (R^2) and root mean square error (RMSE)

4) Visual inspection of spectral unmixing results

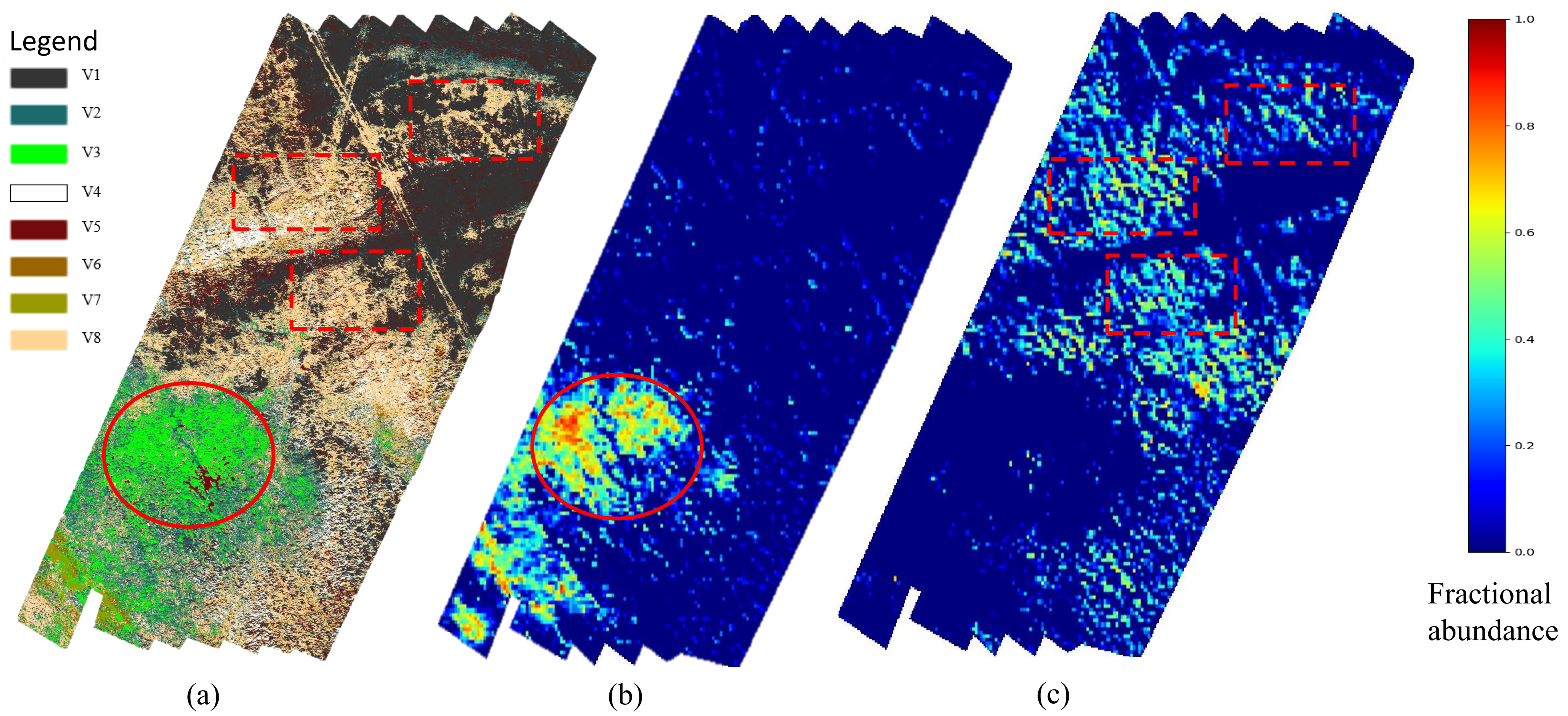


Figure 5. Spectral unmixing results. (a) UAV vegetation map (ground truth). (b) V3 class abundance map from the WorldView-3 image, (c) V8 class abundance map from the Worldview-3 image, Red circles and rectangles highlight the agreement between ground truth and spectral unmixing results for each class.

Conclusion and future study

- In this study, we effectively estimated class-specific abundances of Arctic vegetation from WorldView-3 imagery using a UAV spectral library, showing its potential for large-scale mapping.
- We plan to further validate the approach of this study by involving a diverse range of Arctic plant species and different study sites.

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