Spectral Unmixing-based Mapping of Arctic Plant Species using an Unmanned Aerial Vehicle Spectral Library and a Worldview-3 Satellite Image

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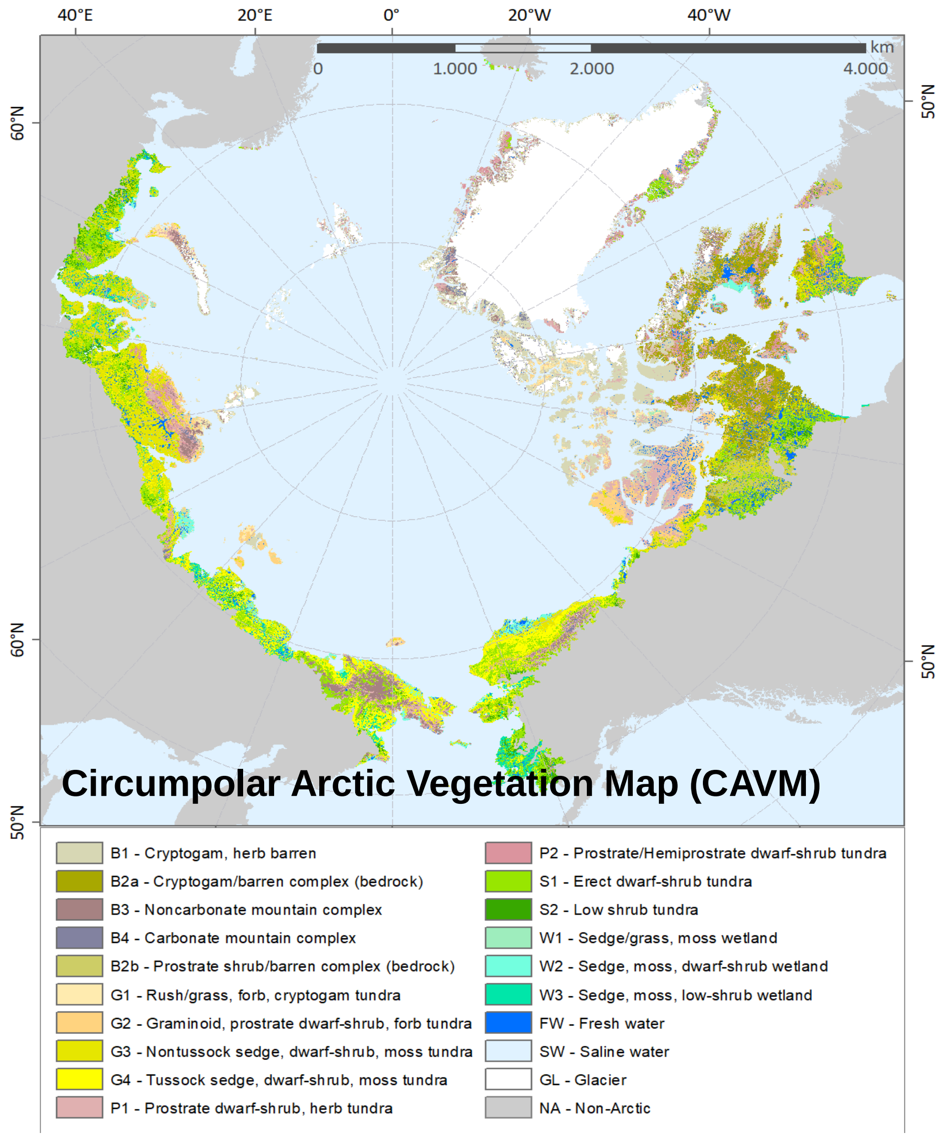
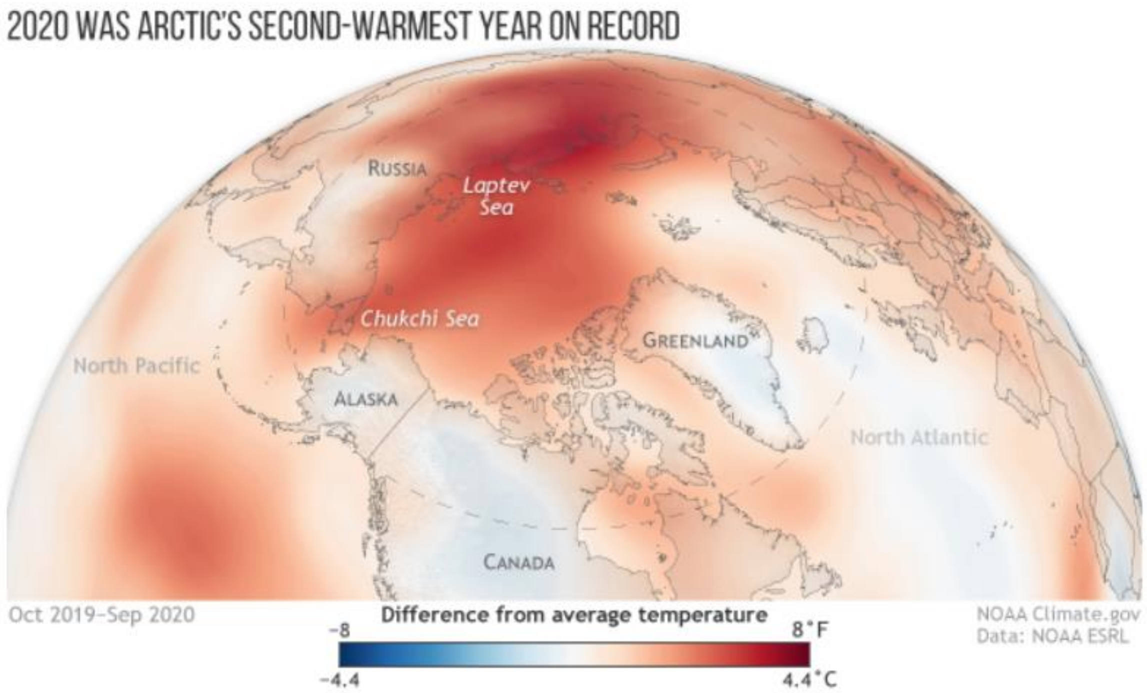
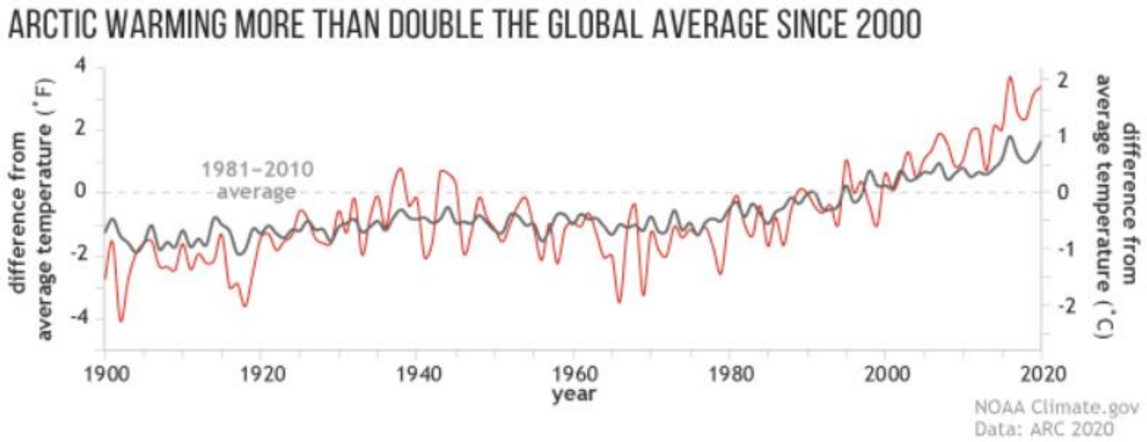






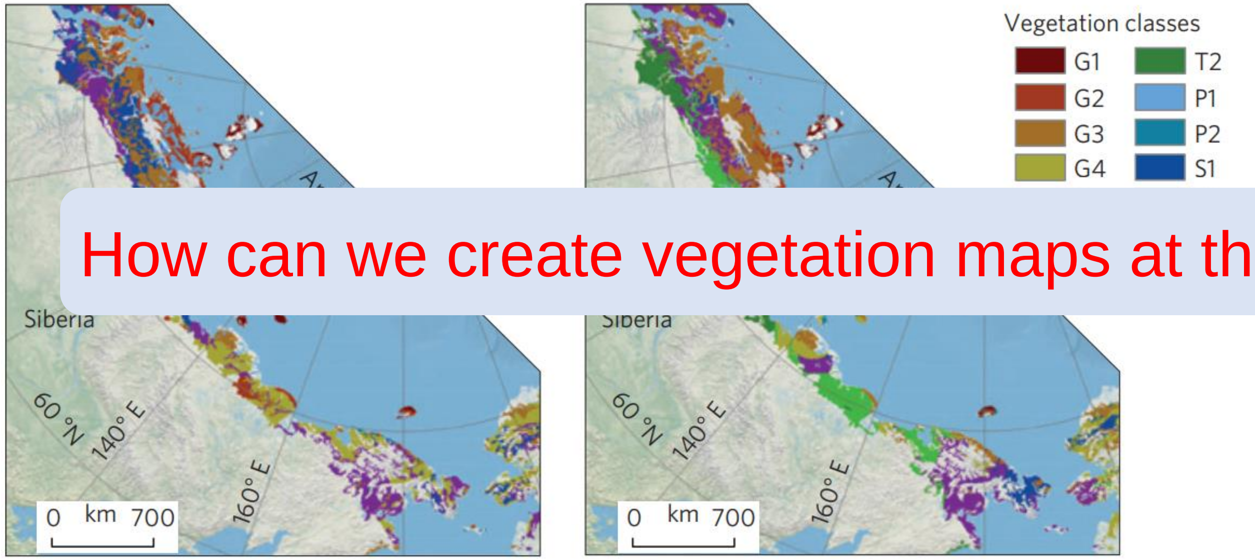
Arctic Vegetation Shifts caused by Climate Change (2050's Scenario)

- In the 2050's scenario (Pearson et al. 20213), at least half of the Arctic vegetation would be redistributed to a different physiognomic class by 2050 due to the global warming

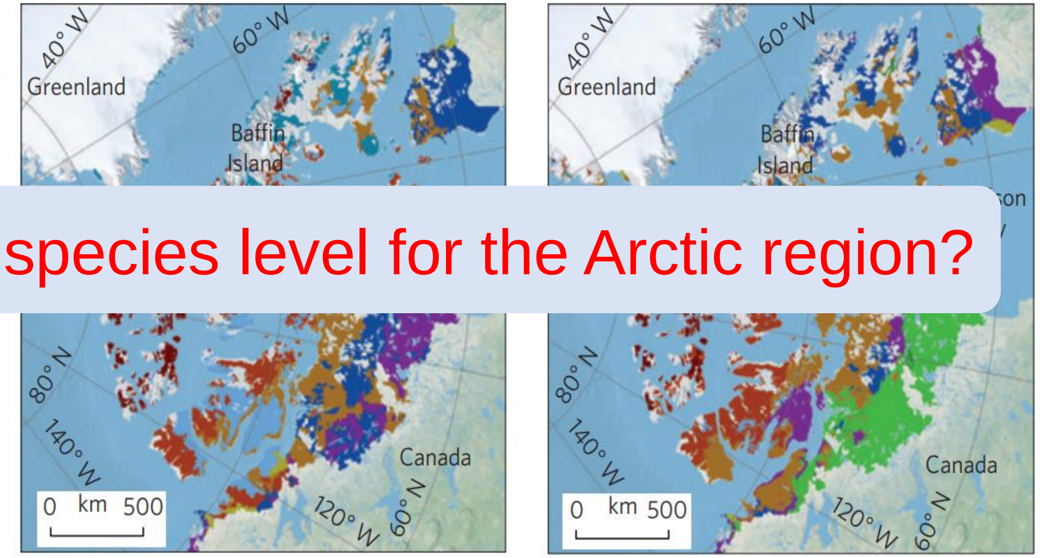
- However, our study aims to understand the shift at species level to determine how individual species are affected by climate change, aiding in biodiversity tracking, ecosystem monitoring, and the development of conversation strategies for specific species.

Vegetation class	Code	Area (km^2)
Rush/grass, forb, cryptogam tundra	G1	137,781
Graminoid, prostrate dwarf-shrub, forb tundra	G2	427,376
Non-tussock-sedge, dwarf-shrub, moss tundra	G3	566,190
Tussock-sedge, dwarf-shrub, moss tundra	G4	335,462
Prostrate dwarf-shrub, herb tundra	P1	396,536
Prostrate/hemiprostrate dwarf-shrub tundra	P2	138,551
Erect dwarf-shrub tundra	S1	687,224
Low-shrub tundra	S2	611,307
Tree-cover mosaic	T1	200,536
Tree cover	T2	204,363

Observed (2000) 2050's scenario



Observed (2000) 2050's scenario



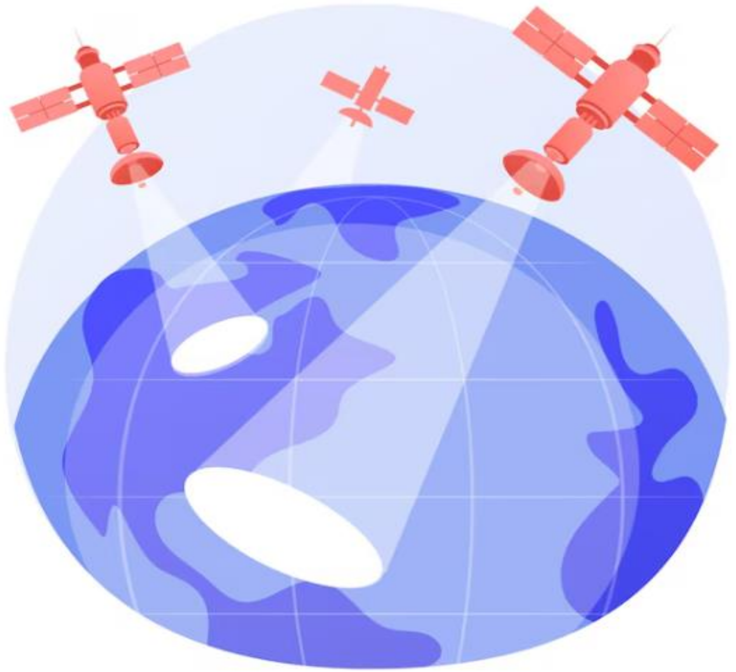
How can we create vegetation maps at the species level for the Arctic region?

Pearson et al., *Nature climate change* (2013)

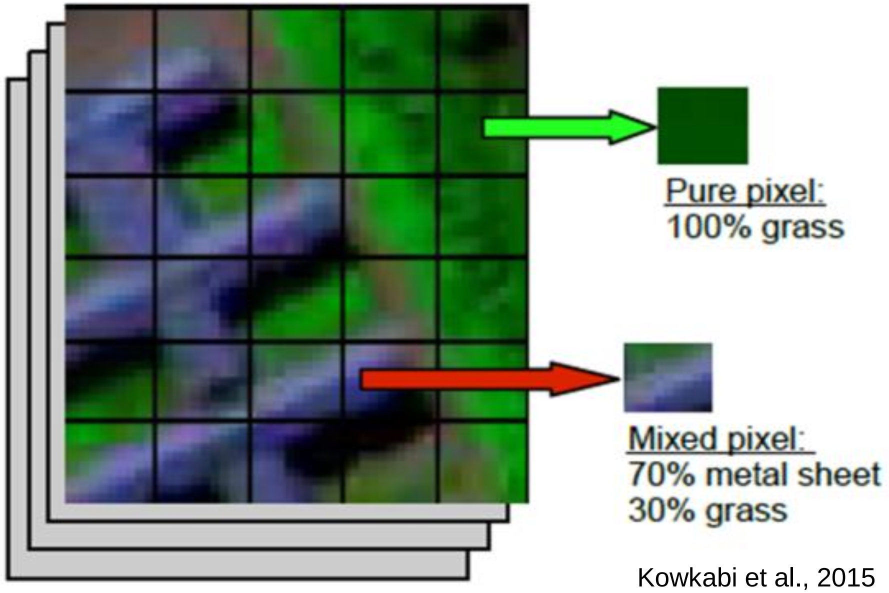
Problems and Strategies

Mapping Arctic plant species remains challenging due to:

- (1) The difficulty in acquiring data from the Arctic region -> Remote Sensing
- (2) Mixed pixel issue caused by low spatial resolution in large-scale remote sensing imagery -> Spectral Unmixing



[The example of the mixed pixel]



Kowkabi et al., 2015

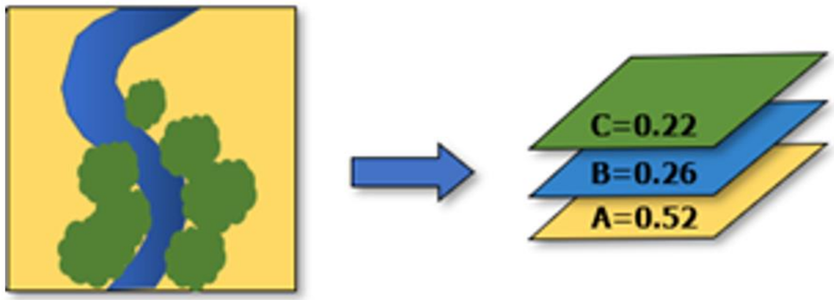
- Remote sensing with the spectral unmixing method is an ideal strategy to address limited data acquisition and the mixed pixel issue

Spectral Unmixing

Spectral unmixing decomposes a mixed pixel into individual spectral signals at the sub-pixel level with two steps:

- (1) identifying a pure spectral signal, called 'endmember'
- (2) estimating the relative abundances of each class from the mixed pixel using endmembers as references

Mixed pixel **Class abundance**



*FCLS: fully constraint least squares

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

M = mixed spectrum
$\boxed{E_j = j^{th} \text{ class pure spectrum}}$
a_j = the fractional abundance of E_j

Two constraints

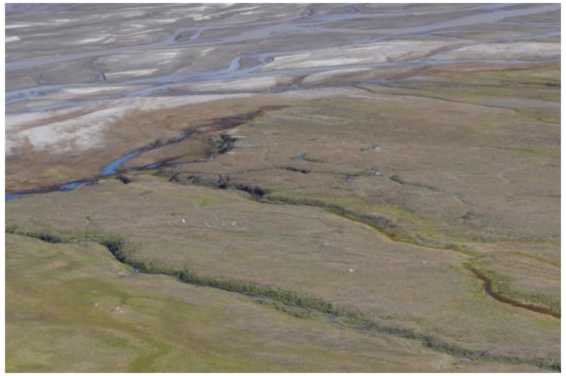
- $\sum_{j=1}^{M} a_j = 1$ (Sum-to-one)
- $0 < a_j$ (Non-negative)

Research objectives

- collecting hyperspectral information for Arctic plant species and developing a spectral library using an UAV
- estimating **class-specific abundances (Abundance maps)** from a mixed pixel of the satellite image using the UAV-based spectral library and the spectral unmixing solution

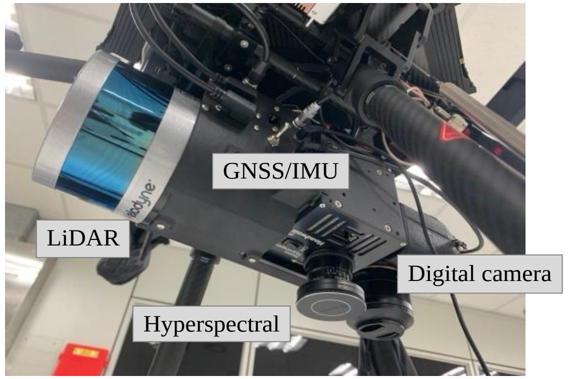
Study Area

- The study area is located in Adventdalen, Svalbard, Norway (78˚09’55’’ N and 16˚00’42’’ E)
- Annual mean surface temperature; 6 ℃, Precipitation; 190 mm

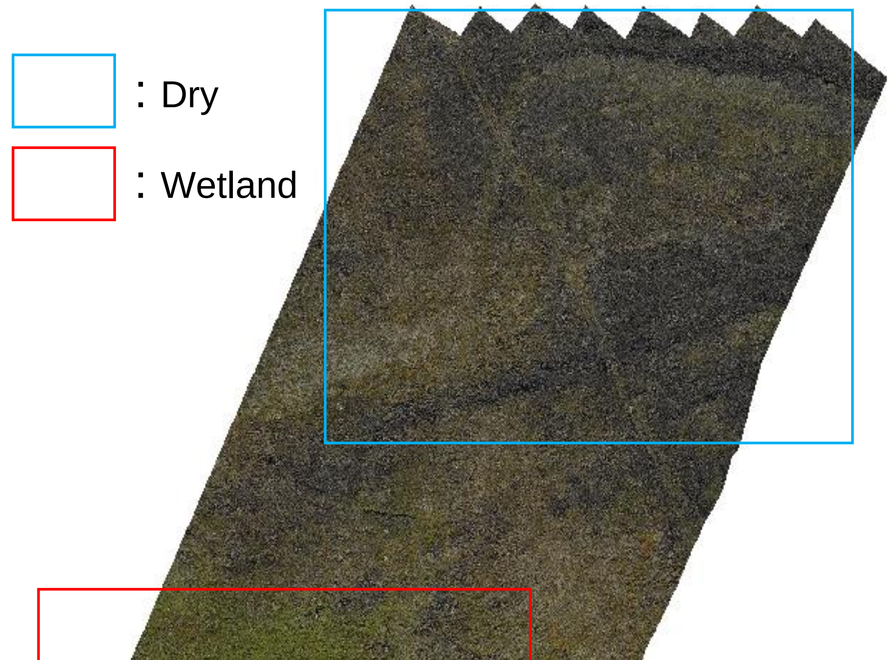


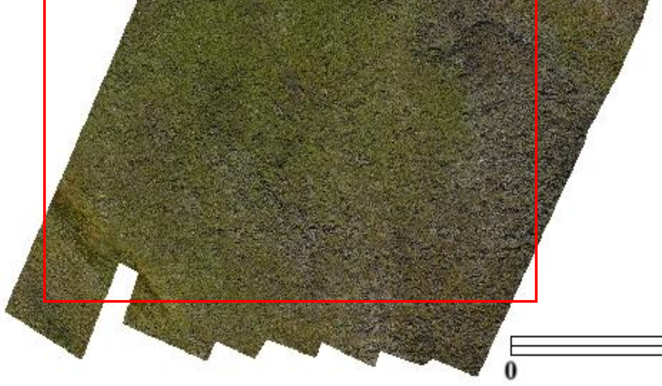
Data Acquisition - UAV spectral measurement

[Hyperspectral and high-resolution RGB cameras on DJI PRO 600]



[Summer field study in 2022. July]





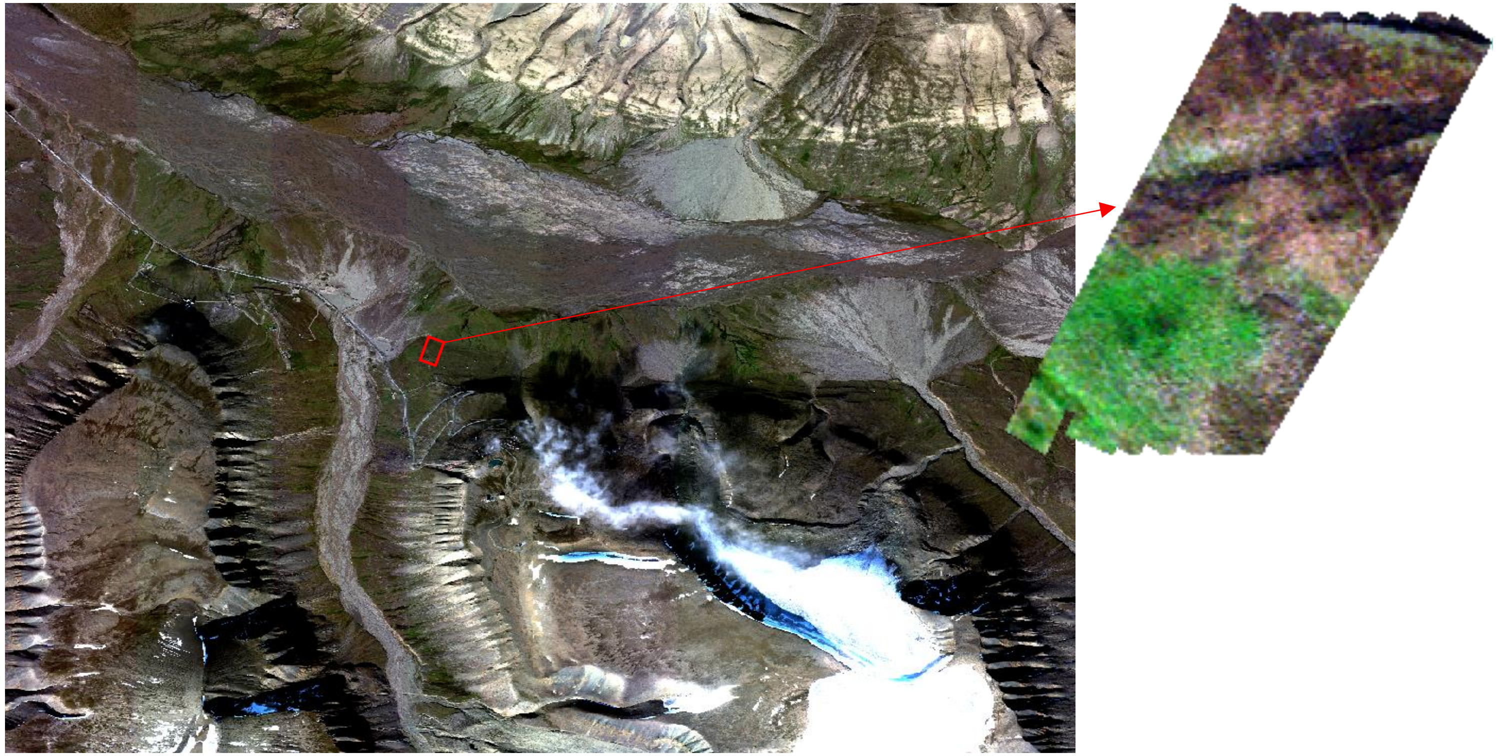
Data Acquisition - Worldview-3 Satellite Imagery

Worldview-3 is a commercial Earth observation satellite operated by DigitalGlobe

- includes 8 VNIR spectral bands with central wavelengths at 425, 480, 545, 605, 660, 725, 832.5, and 950 nm
- offers high spatial resolution with 1.24 m in the VNIR range

[The Worldview-3 satellite]

[Worldview-3 imagery with study area]

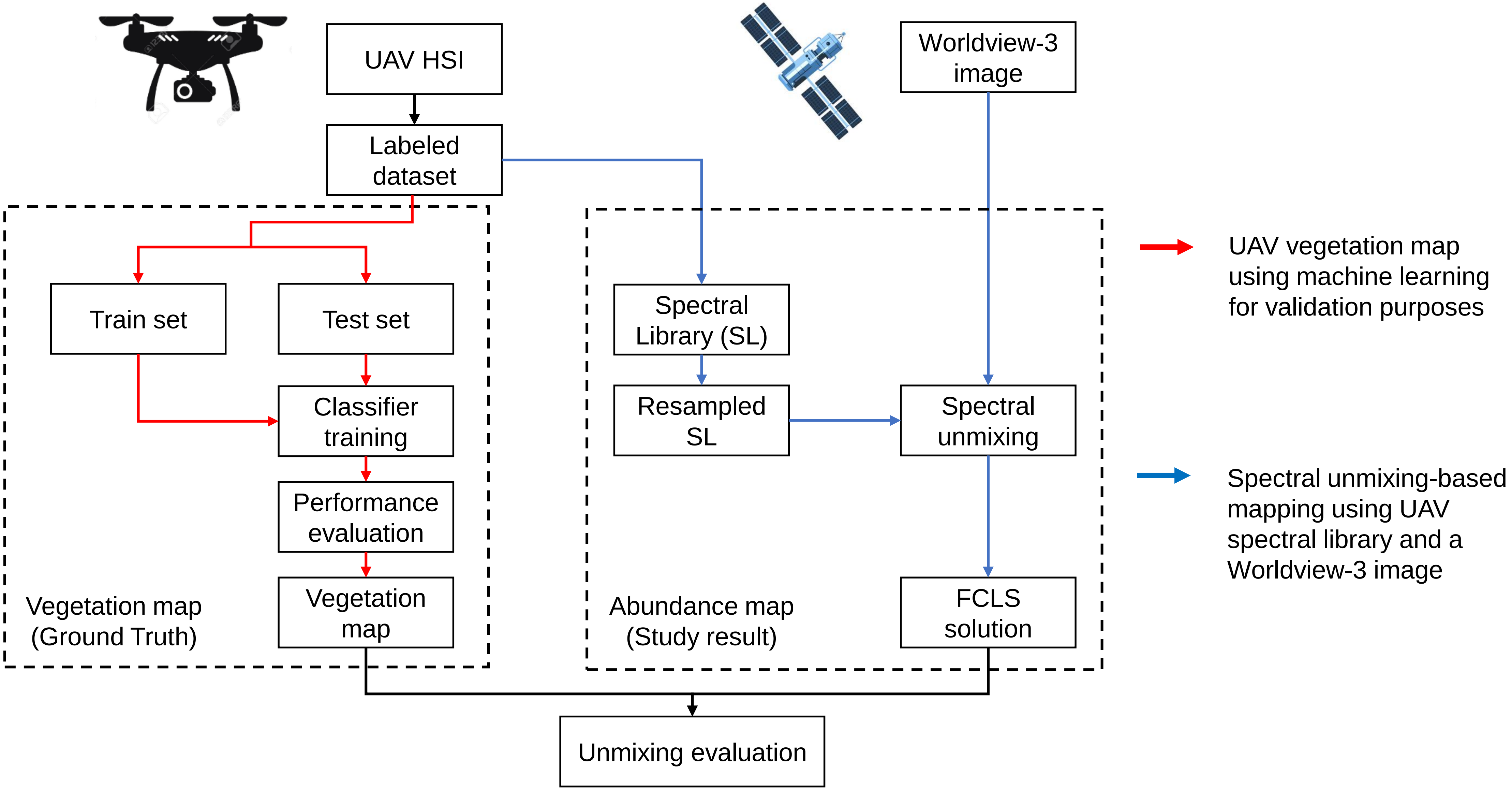


Data Summary

- A description of the UAV hyperspectral image and the Worldview-3 image used in the study
- The UAV high-resolution RGB was used for validation purposes and identifying ground truth

	UAV hyperspectral	Worldview-3 multispectral	UAV high-resolution RGB (validation purpose)
Spectral range	VNIR (400 – 1000 nm)	VNIR (400 – 1000 nm)	RGB; Red, Green, Blue
Spectral bands	137 bands (after binning)	8 bands	3 bands
Spatial resolution	0.4 m	1.24 m	0.06 m
Date of acquisition	2022-07-07	2021-08-08	2022-07-07
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	-

Research Flow



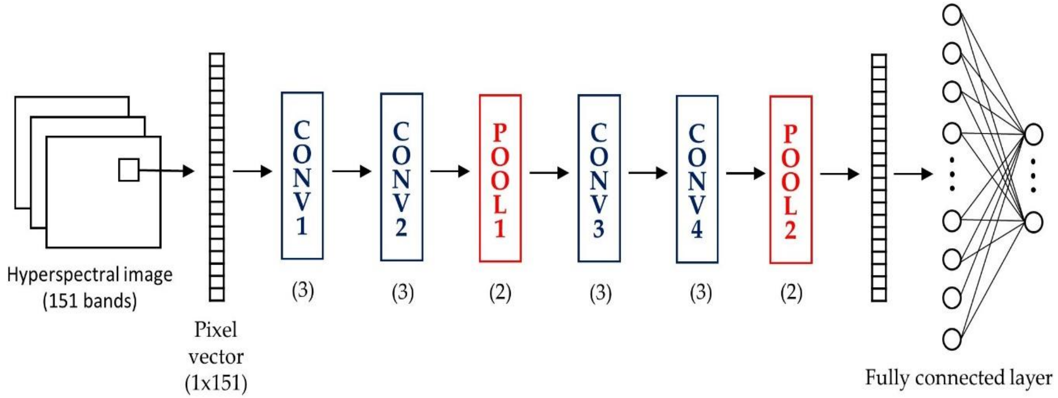
Labeled Datasets and the UAV Vegetation Map

[The pixels associated with the classes were identified and labeled the high-resolution RGB imagery and field surveys (visual inspection)]

[Table for class description investigated in the study]

Class ID	Class name	Train	Test
V1	*Cassiope tetragona* (dead)	1000	250
V2	*Cassiope tetragona* (healthy) & *Dyras octopetala*	1000	250
V3	*Equisetum arvense* & *Salix Polaris*	1000	250
V4	*Luzula confusa*	1000	250
V5	Soil	1000	250
V6	Moss (dry region)	1000	250
V7	Moss (wet region)	680	170
V8	*Salix polaris* & moss	1000	250
-	Total	7680	1920

[The architecture of a one-dimensional convolutional neural network (1D-CNN) used in this study]



Yang et al., 2023

- A spectral library was developed using the mean spectrum per class of the labeled datasets and used for unmixing a Worldview-3 image.
- The dataset was split into two datasets to train and test machine-learning classifier, and 1D-CNN classifier was used to create vegetation map for validation purposes.

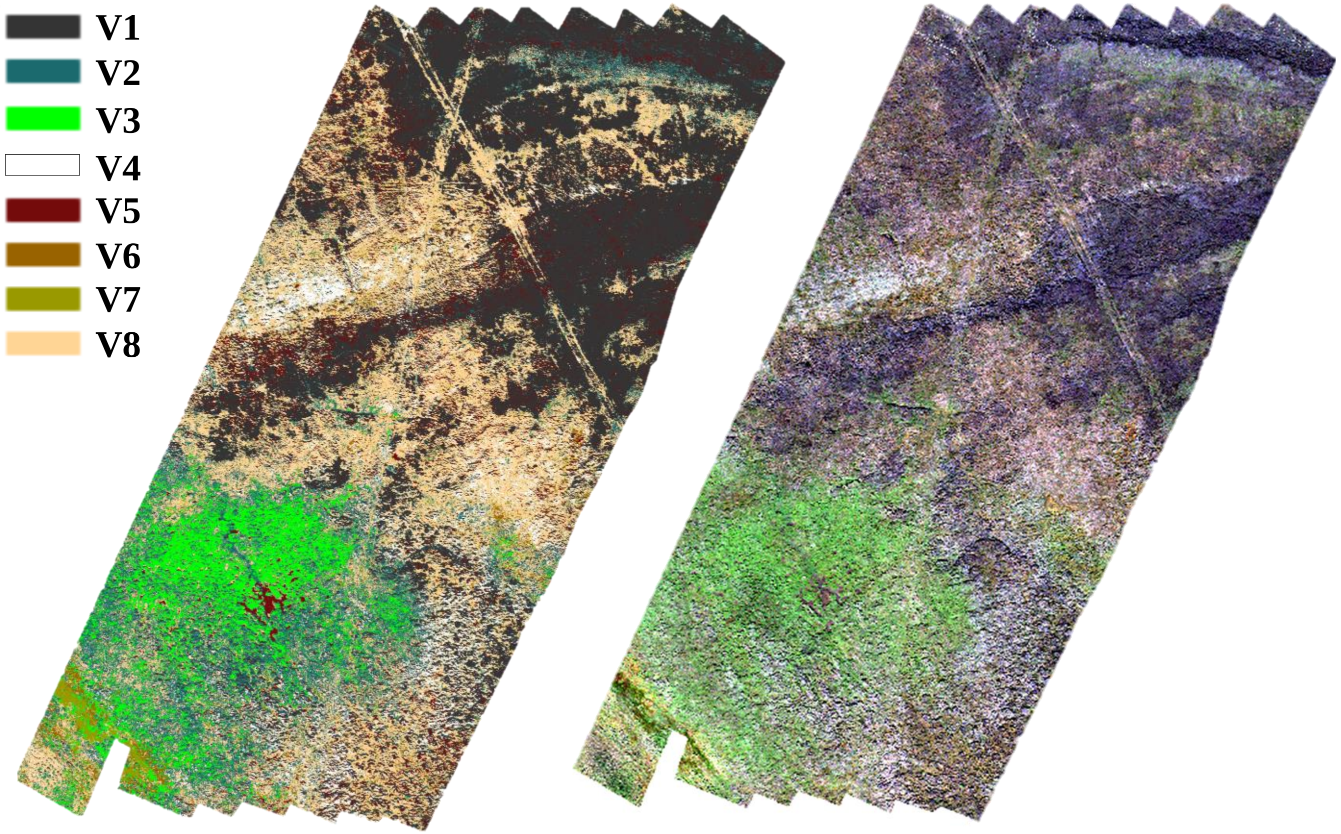
Machine Learning-based Classification (UAV Vegetation Map)

- Classification of the UAV hyperspectral image using a 1D-CNN classifier, which was used as the ground truth

[Statistical accuracy for quantitative evaluation]

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

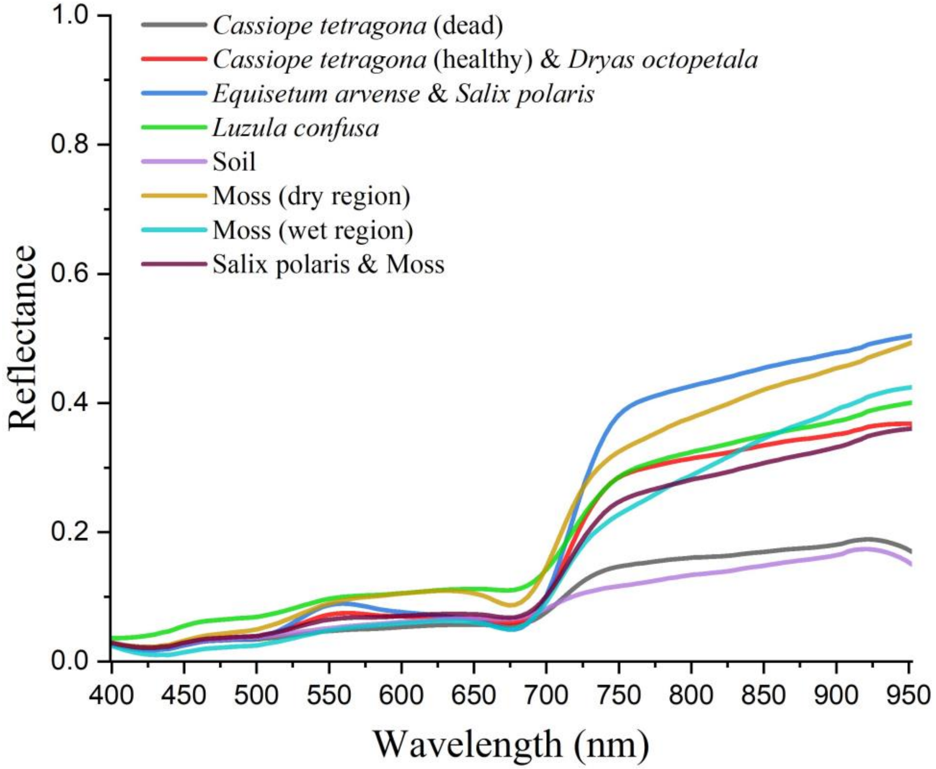
[Comparison of image classification results for qualitative evaluation]
(Left: Vegetation map, Right: True color image)



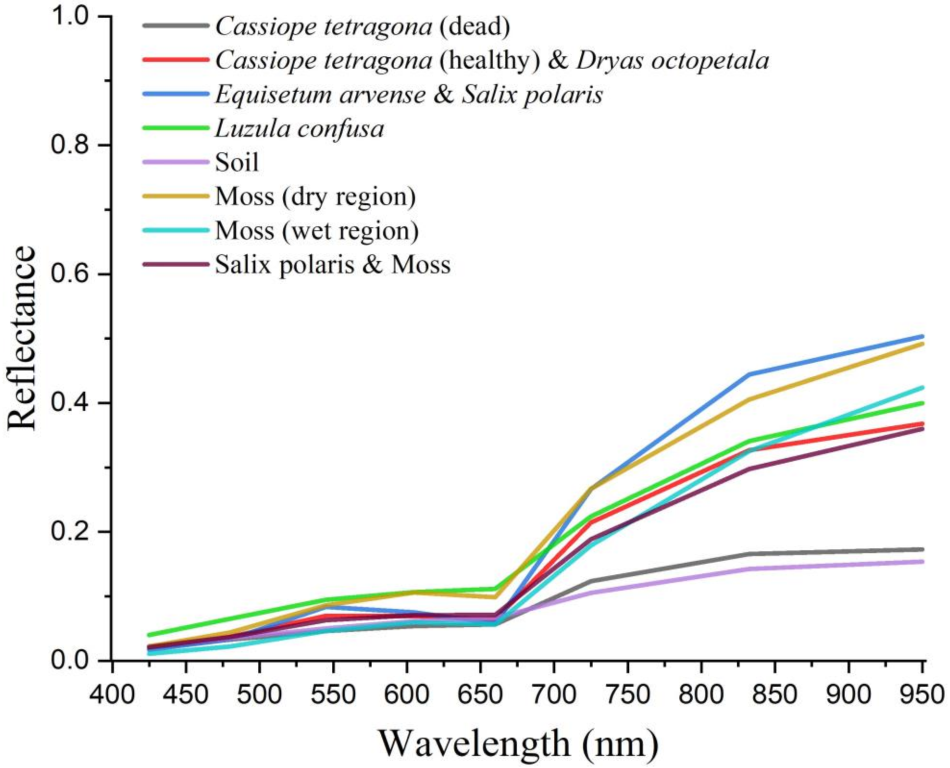
UAV Spectral Library

- Developed a spectral library for Arctic plant species using labeled dataset acquired the UAV-hyperspectral image
- Converted the UAV spectral library (137 bands) into a resampled spectral library (8 bands) using linear interpolation for spectral compatibility with the satellite image

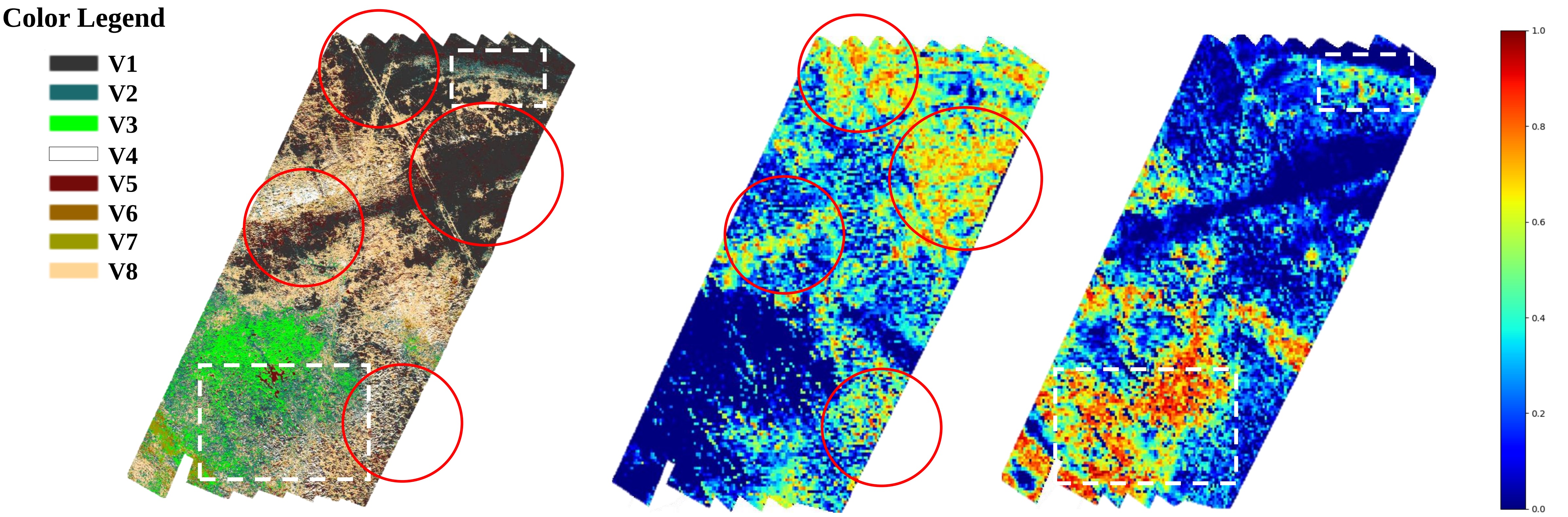
[UAV spectral library]



[Resampled spectral library]



Unmixing Results (1) - Qualitative Evaluation



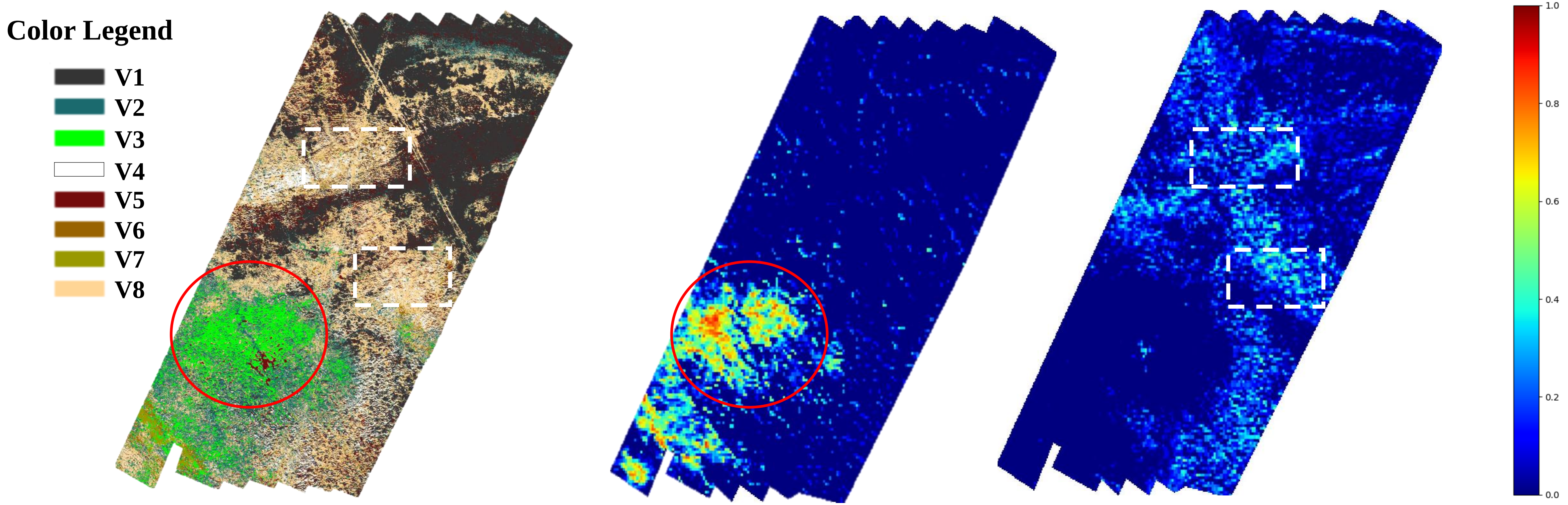
UAV Vegetation map (ground truth)

(1) Abundance map *Cassiope tetragona* (dead)

(2) Abundance map *Cassiope tetragona* (healthy) & *Dyras octopetala*

Fractional abundance (0-1)

Unmixing Results (2) - Qualitative Evaluation



UAV Vegetation map (ground truth)

(3) Abundance map *Equisetum arvense* & *Salix Polaris*

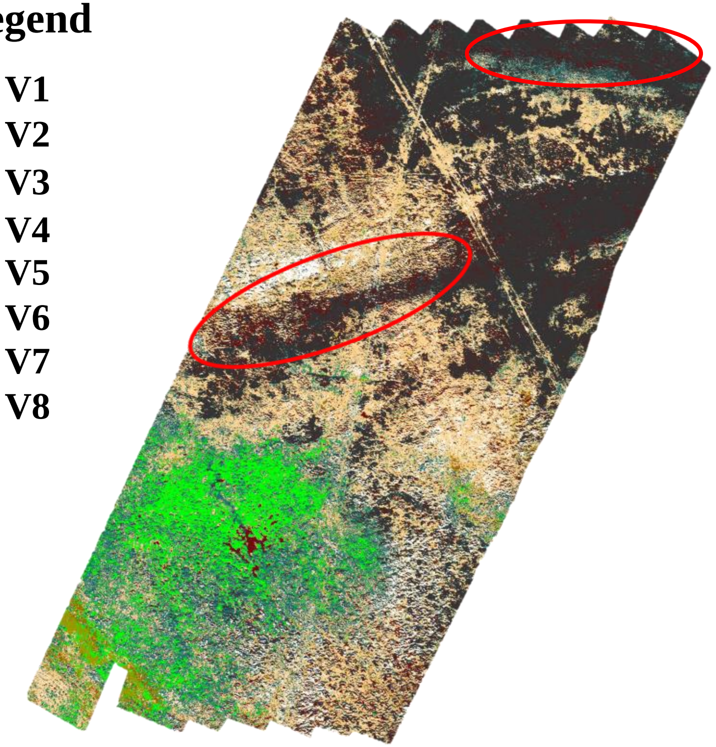
(4) Abundance map Graminoid (dead) & *Luzula confusa*

Fractional abundance (0-1)

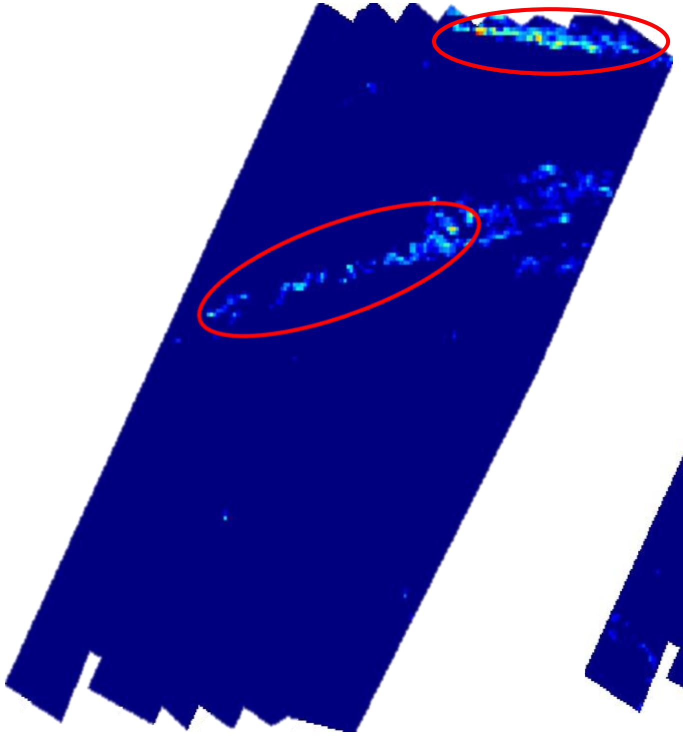
Unmixing Results (3) - Qualitative Evaluation

Color Legend

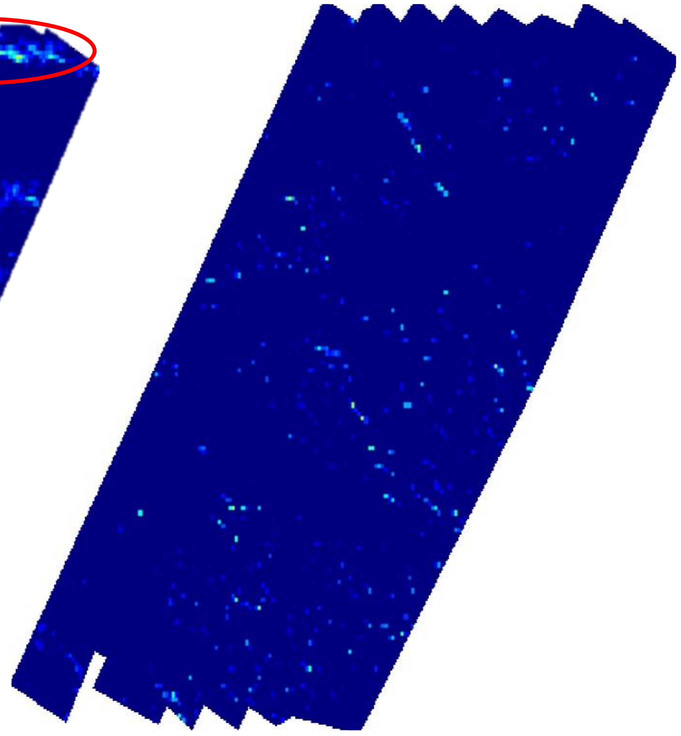
- V1
- V2
- V3
- V4
- V5
- V6
- V7
- V8



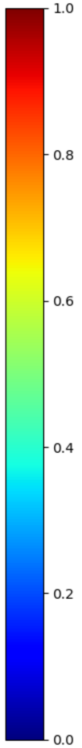
UAV Vegetation map
(ground truth)



(5) Abundance map
Soil

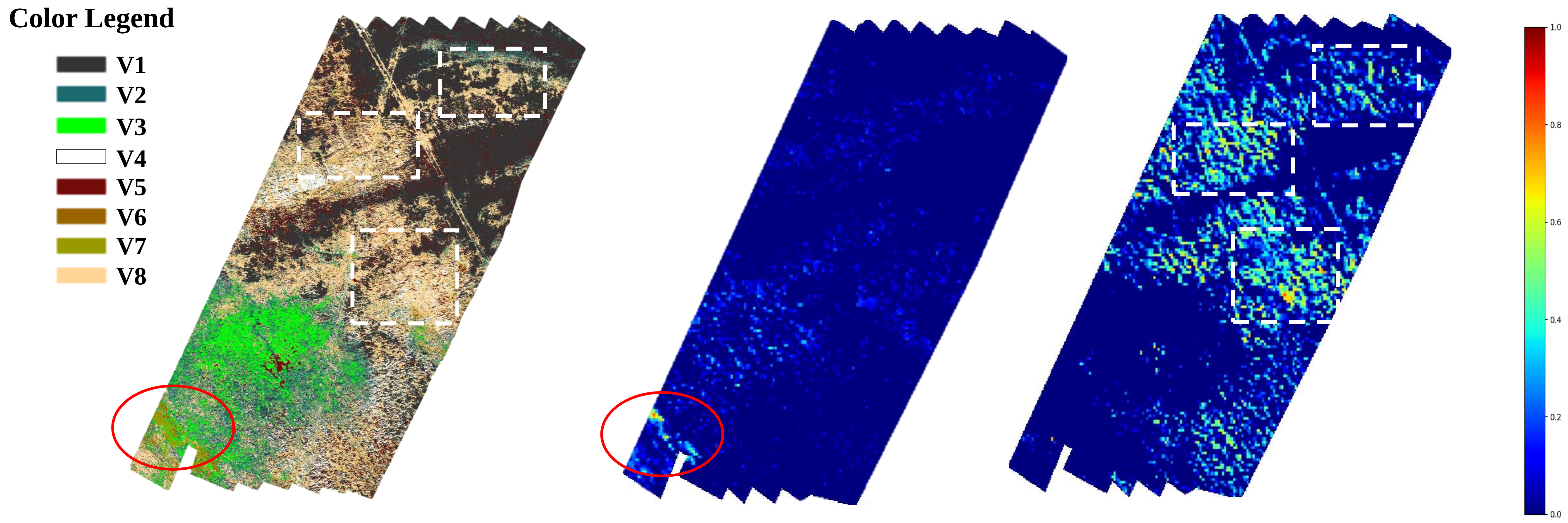


(6) Abundance map
Moss (dry region)



Fractional abundance (0-1)

Unmixing Results (4) - Qualitative Evaluation



UAV Vegetation map
(ground truth)

(7) Abundance map
Moss (wet region)

(8) Abundance map
Salix polaris & moss

Fractional abundance (0-1)

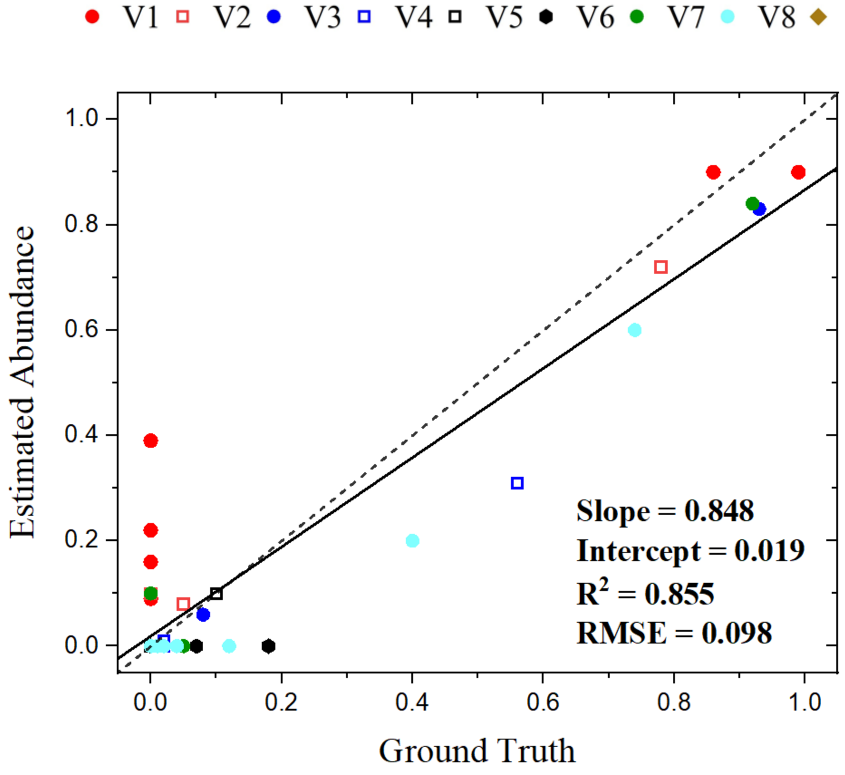
Unmixing Results - Statistical Evaluation

- Comparison of classification results for a UAV hyperspectral region (30 x 30 pixels, Ground truth) and spectral unmixing results for a WorldView-3 single pixel. The validation of spectral unmixing was performed using a total of eight regions.

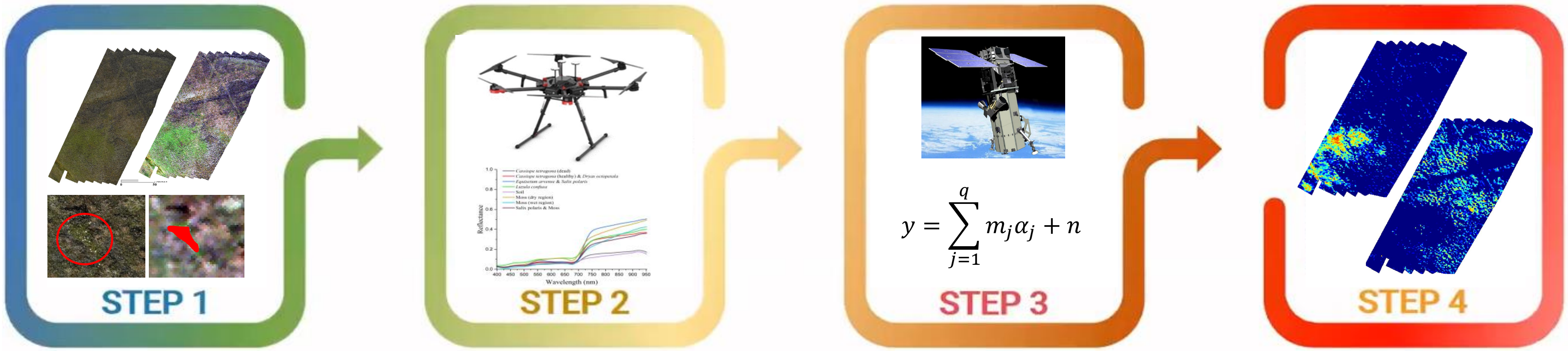
[Average fractional abundances of the ground truth and the spectral unmixing results]

Fractional Abundance (Average)	Class								
	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

[Statistical evaluation using coefficient of determination (R^2) and root mean square error (RMSE)]



Summary & Future plans



Data acquisition & Data labeling

UAV-based Spectral library

Unmixing satellite pixels

Class-specific abundance map

- In this study, we effectively estimated class-specific abundances of Arctic plant species using Worldview-3 imagery combined with a UAV spectral library, demonstrating the potential for large-scale mapping of Arctic vegetation.
- We plan to further validate our approach by including a broader range of Arctic plant species and various study sites.
- We further aim to create more detailed and accurate maps using a ground-based spectral library (J. Yang et al., 2023)
- In future studies, I aim to apply these methodologies to Lunar and Mars exploration for surface mapping.

Thank you for your attention!

ACKNOWLEDGEMENT

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