Mapping of High-elevation Alpine Grassland Communities Based on Hyperspectral UAV Measurements

Levente Papp[1,2], Abraham Mejia-Aguilar[2], Ruth Sonnenschein[2], Rita Tonin[3], Michael Loebmann[3] Clemens Geitner[4], Martin Rutzinger[4], Andreas Mayr[4] and Stefan Lang[1]

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Mountain environments are particularly vulnerable to ongoing climatic and environmental changes. Specifically, alpine grasslands are seriously threatened by shallow erosion which has been increasingly detected during the last decades on alpine meadows and pastures. It has been suggested that a high plant species diversity of alpine grassland communities may increase the erosion resistance of soils, mainly through positive effects on root length, number of root tips and foliage abundance. Moreover, high plant biodiversity has shown to stabilize water channels by giving slope instability.

OBJECTIVES

Mapping the grassland communities based on high precision ground measurements and hyperspectral remotely sensed datasets:

+ Investigate and delineate the main lawn communities present in the area
+ Define the dominant grassland species and determine the approximate coverage of them
+ Based on spectral signatures distinguish the main grassland communities
+ Using remotely sensed datasets classify the different vegetation types in the area

Our study area (Fig.1) is a steep, approximately 5 ha large site, in Puez-Geisler National Park, Funes Valley. It is at 2190-2300 m a.s.l. and highly endangered by shallow erosion.

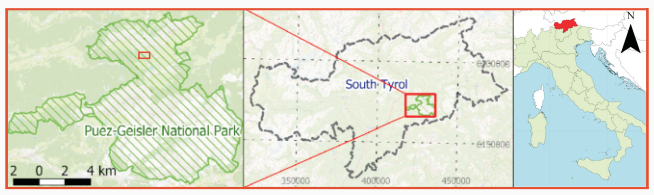

Figure 1. Study area:Funes Valley in Puez-Geisler National Park

MATERIALS & METHODS

During the field survey, within the framework of the ERODYN project, among others, we conducted a botanical survey and UAV flights. The ground measurements were taken, using 50x50 centimeters wooden frames (quadrats) - Fig.2.

UAV flight with RGB camera

UAV flight with Hyperspectral Rikola camera:
- 40 bands: 506-896 nm
- 5 cm spatial accuracy

3 measurements with Spectroradiometer (Spectra Vista) from 1 meter high in each quadrat
- range: 340-2500 nm

Sampled vegetation

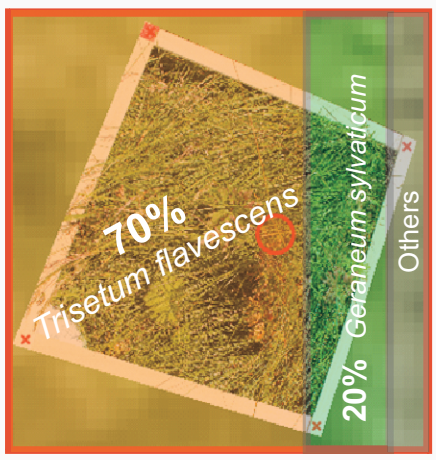

Figure 2. Results of the detailed botanical survey in a quadrat of Class 3

Based on the quadrats and on the botanical survey we were able to define 5 main vegetation classes. These classes were delineated on the field and these, high precision delineated areas (GNSS RTK GPS) served as ground truth data.

For validation, we used the areas of quadrats whose exact contents were precisely defined during the study.

RESULTS

The reached overall accuracy is 75.57% using Support Vector Machine (SVM) classification - Table 1.

Confusion matrix - Ground truth (percent)						
	Class 01	Class 02	Class 03	Class 04	Class 05	Total
Class 01	61.61	0	0.78	0	0	7.33
Class 02	0	32.19	0	0	2.88	5.29
Class 03	38.39	35.36	89.3	0	0	22.47
Class 04	0	1.06	7.83	80.15	3.69	30.97
Class 05	0	31.4	2.09	19.85	93.43	33.95
Total	100	100	100	100	100	100

Table 1. The validation of the SVM classification results for the 5 defined grassland classes according to confusion matrix

False positive results were not significant, misclassification occurs to a lesser extent. The main challanges were the overlapping species and the similarities of the spectral signature between classes.

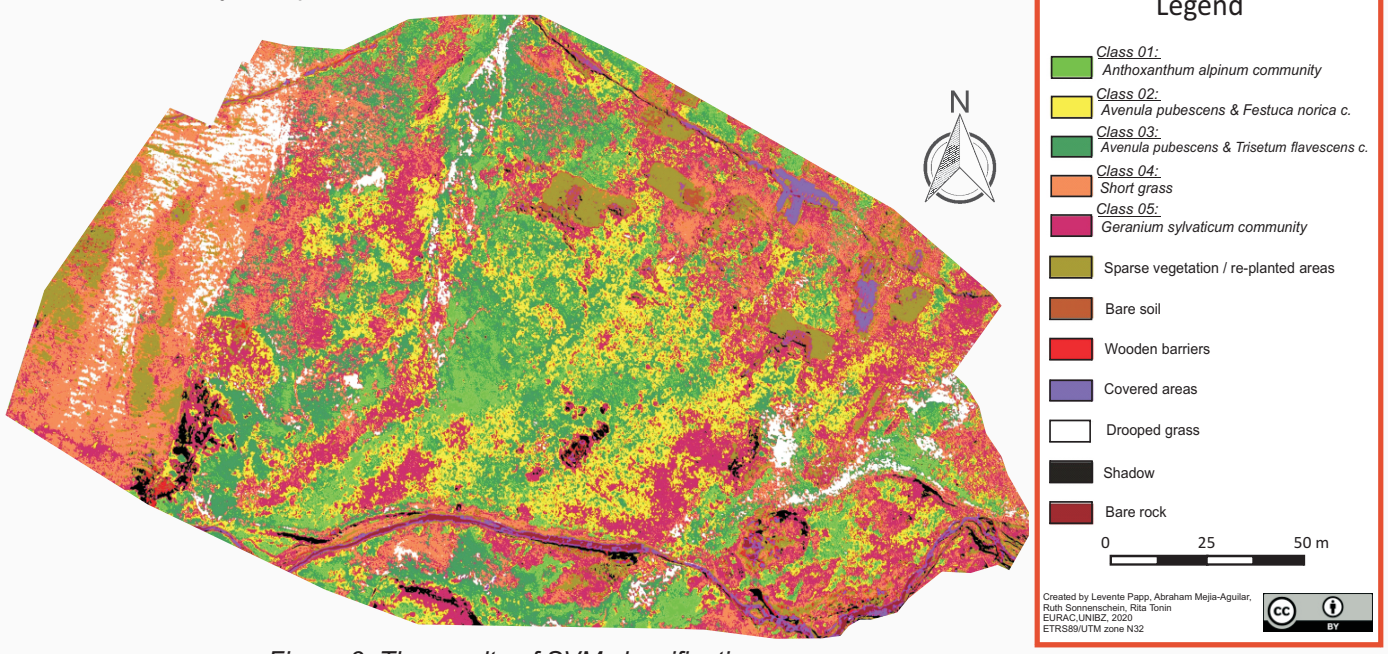

Figure 3. The results of SVM classification

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Objectives

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- Based on spectral signatures distinguish the main grassland communities
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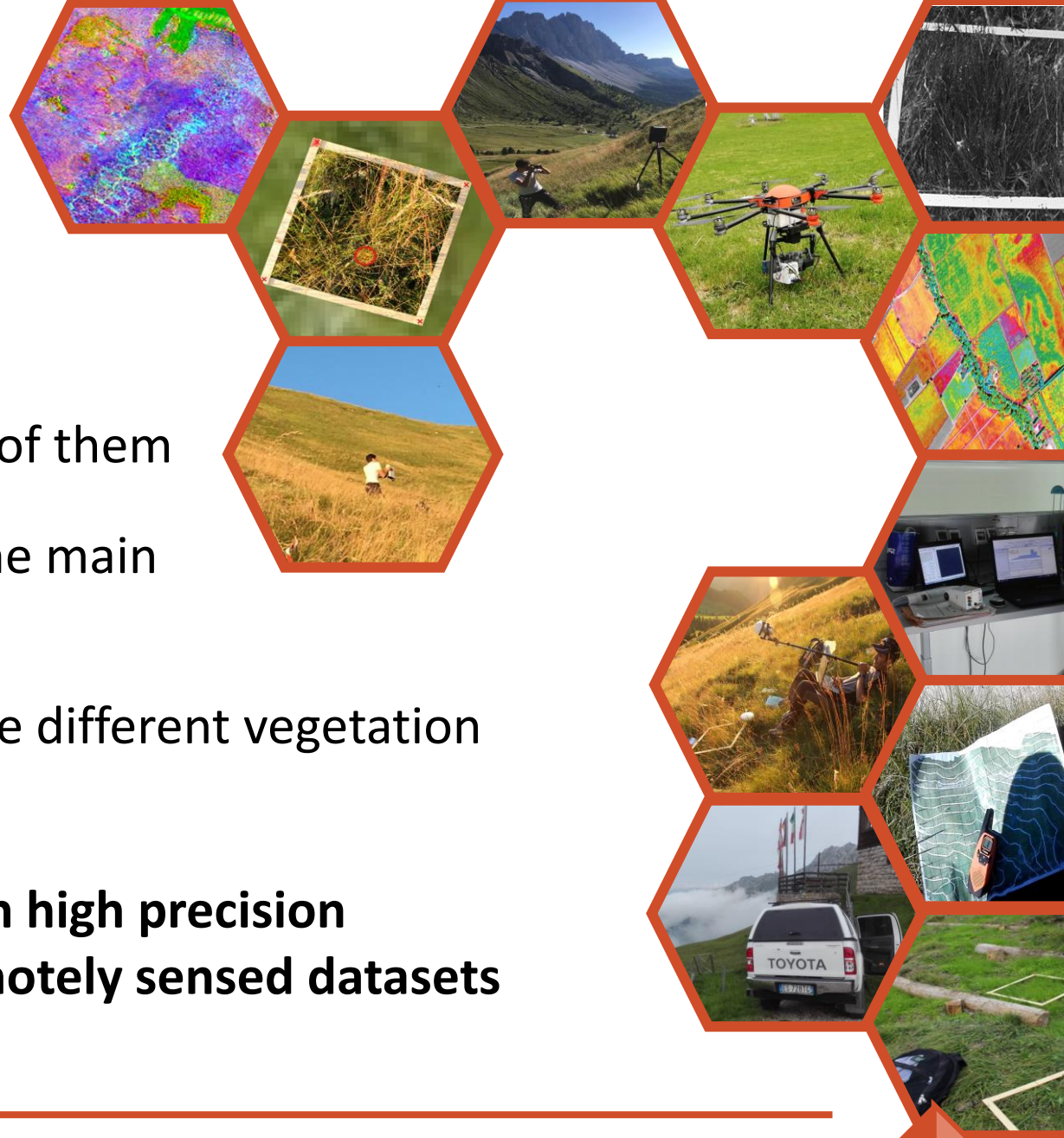
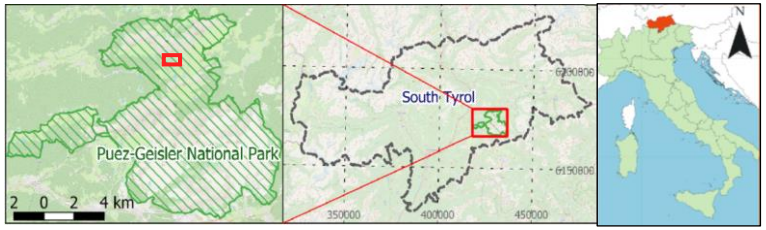
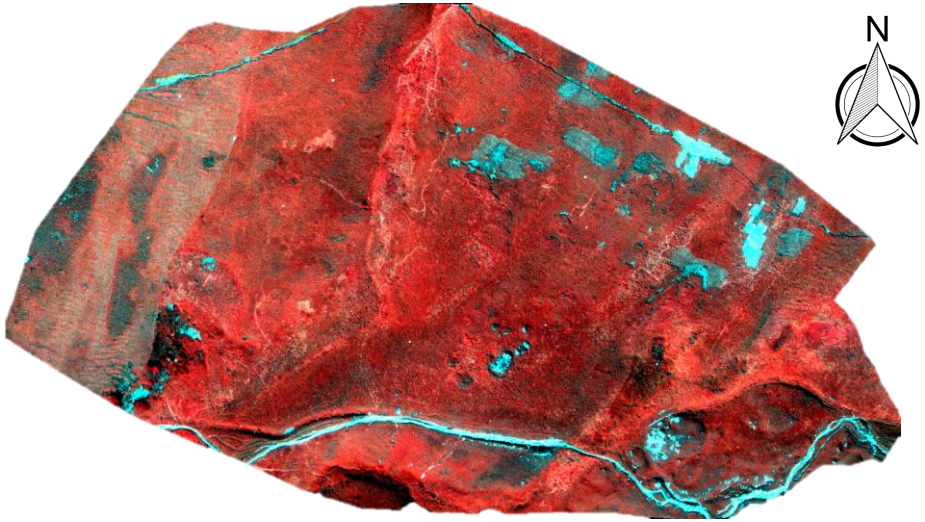


Mapping the grassland communities based on high precision ground measurements and hyperspectral remotely sensed datasets

Study area

- Funes valley, in Puez-Geisler National Park, South Tyrol, Italy
- 2190-2300 m a.s.l.
  → precipitous area
- Endangered by shallow erosion

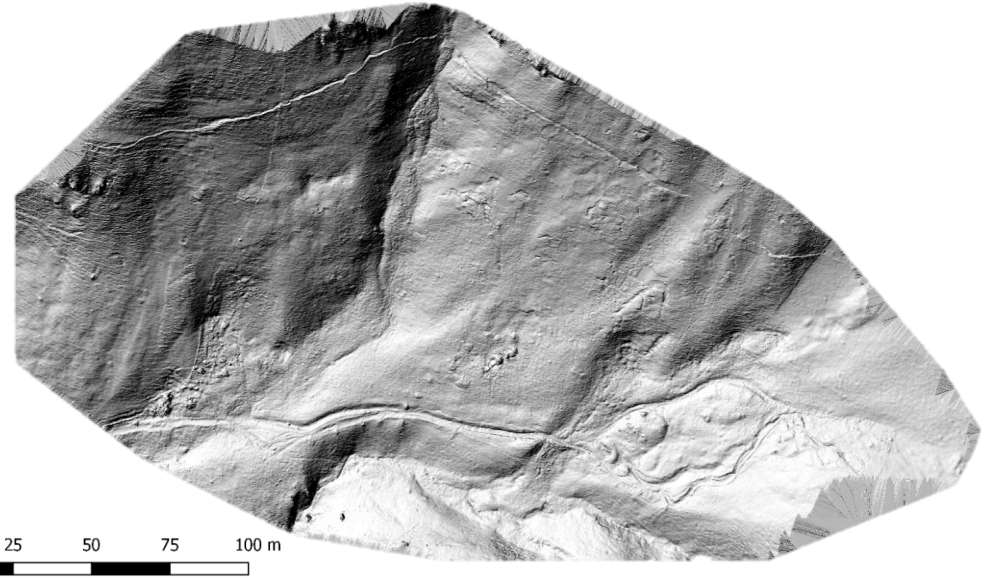




Funes valley study area near-infrared composite (896 nm)

- Area: 5 ha
- Field trips:
  → 23/08/2019
  – Botanical surveys

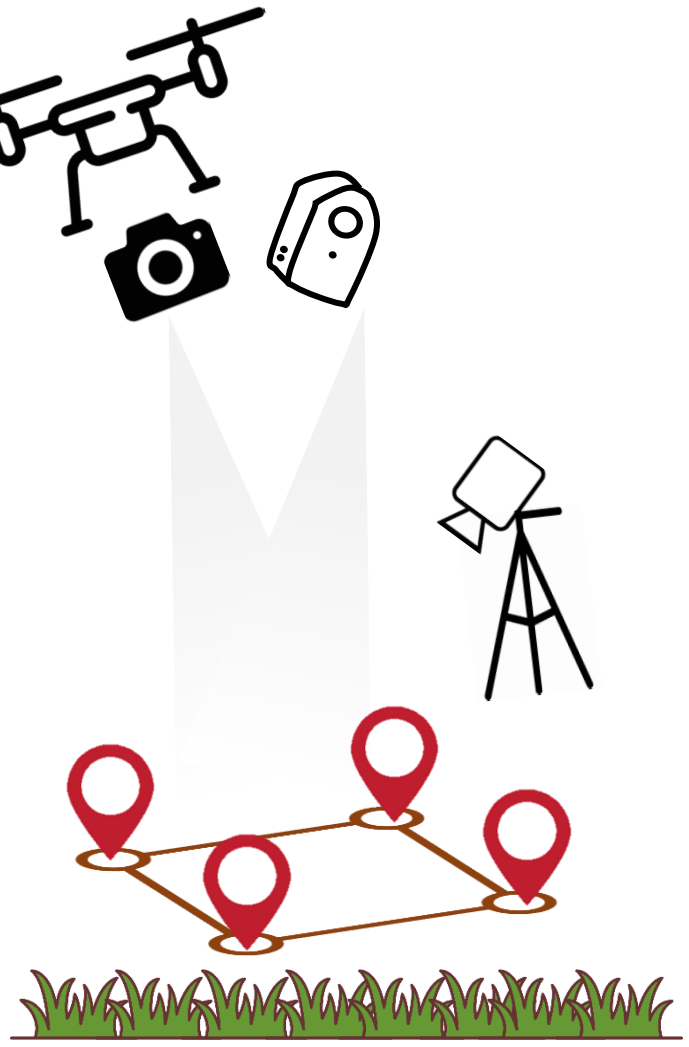
  → 04/09/2019
  – UAV flights
  – Field measurements



Funes valley study area RGB composite

Funes valley study area digital elevation model

Measurements



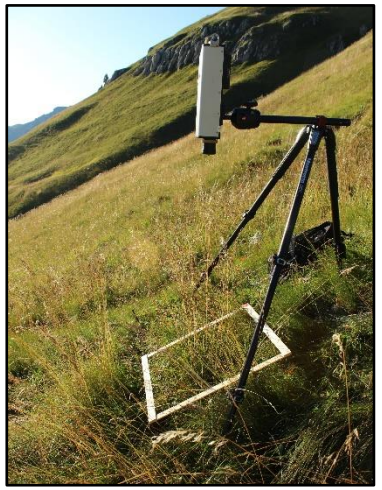
UAV flights

RGB image

Hyperspectral image: Rikola camera:
40 bands: 506-896 nm
5 cm spatial accuracy

Field measurements (Quadrats) – 50x50 cm:

3 measurements with Spectroradiometer (Spectra Vista HR-1024i) from 1 meter high
Range: 340-2500 nm
(+ Photos with spectroradiometer, for positioning)



High quality RGB images

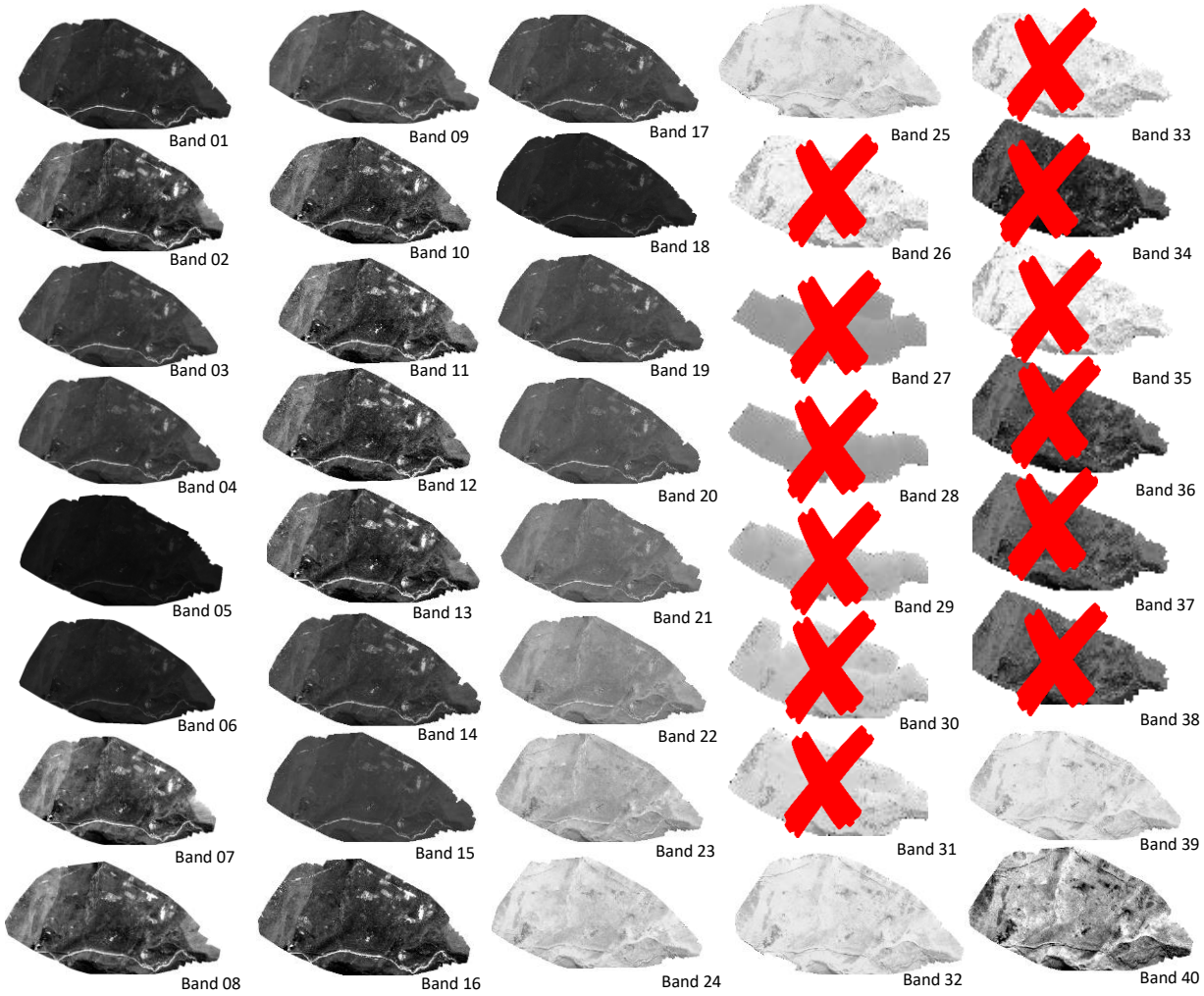
Hyperspectral images of quadrats

Sampled vegetation

+ GNSS RTK GMPS measurements of the corner of quadrats

Measurements

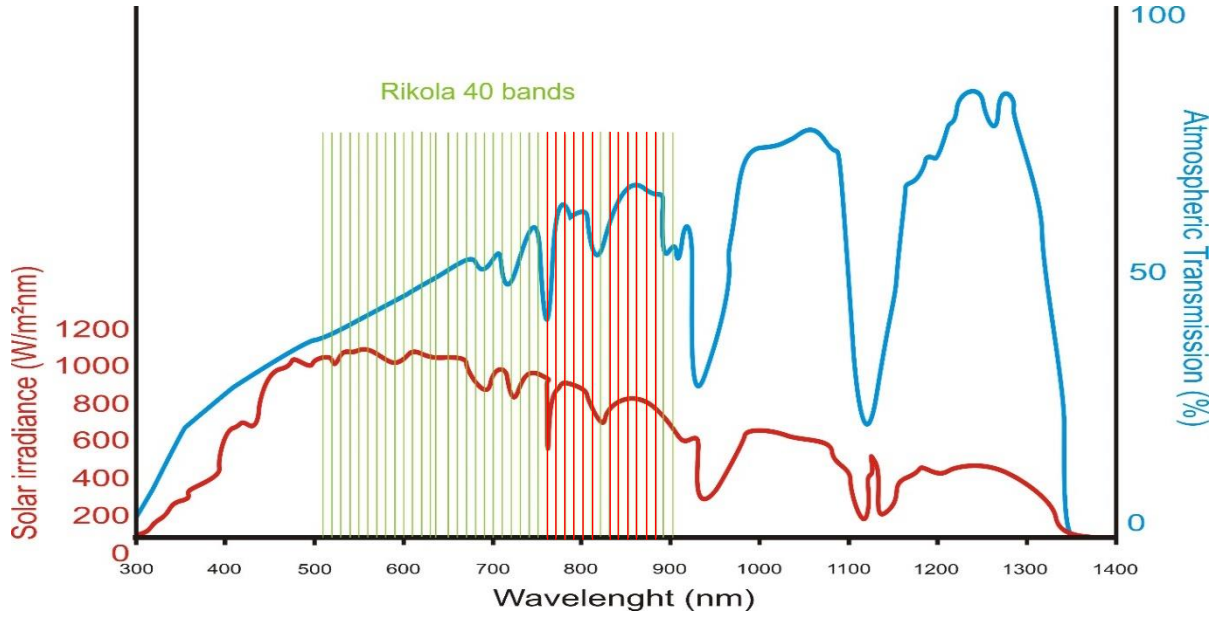
Hyperspectral UAV measurements



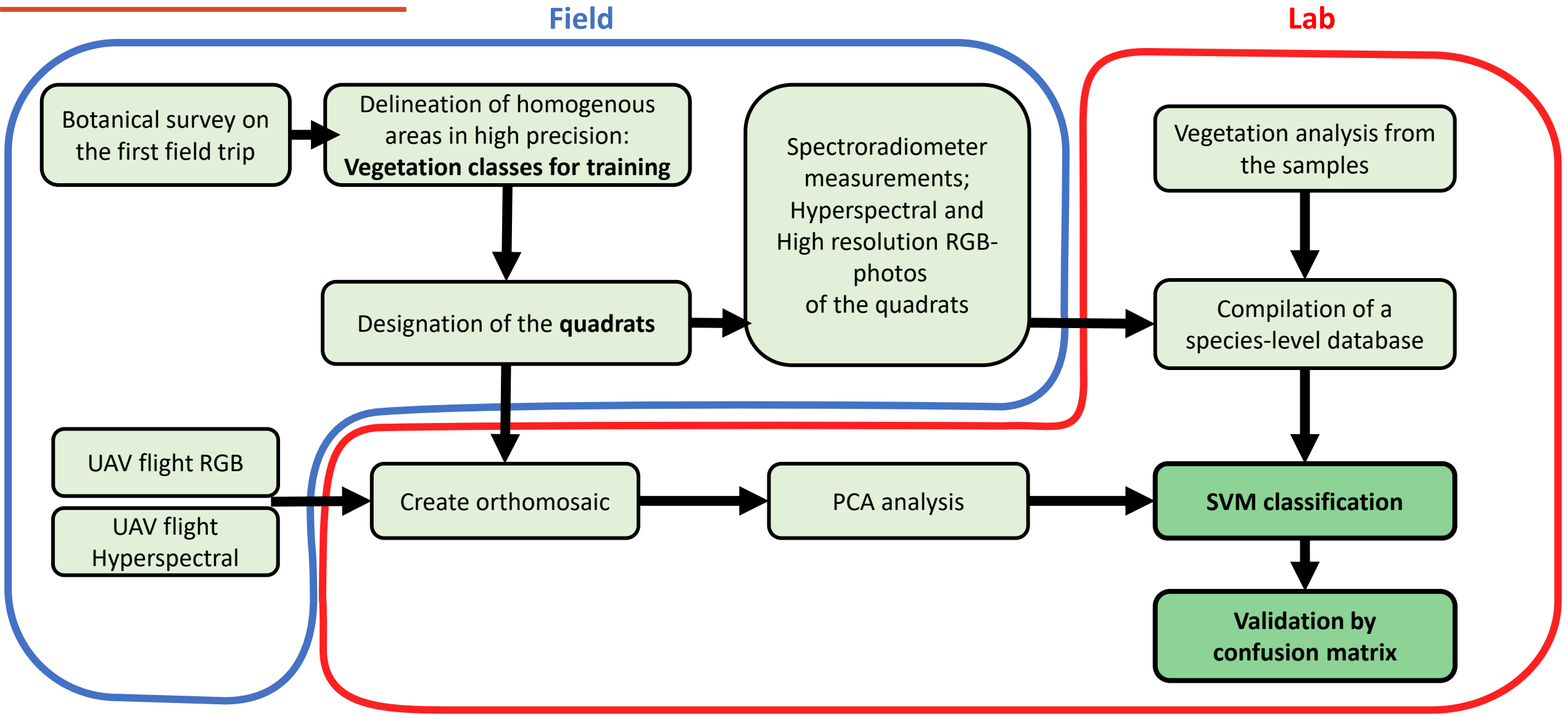
Excluded bands:
(12)

Band 26 – 756,129 nm
Band 27 – 766,380 nm
Band 28 – 776,245 nm
Band 29 – 786,129 nm
Band 30 – 796,154 nm
Band 31 – 806,339 nm
Band 33 – 825,500 nm
Band 34 – 835,804 nm
Band 35 – 846,697 nm
Band 36 – 855,982 nm
Band 37 – 866,602 nm
Band 38 – 877.456 nm

28 bands remaining for the classification

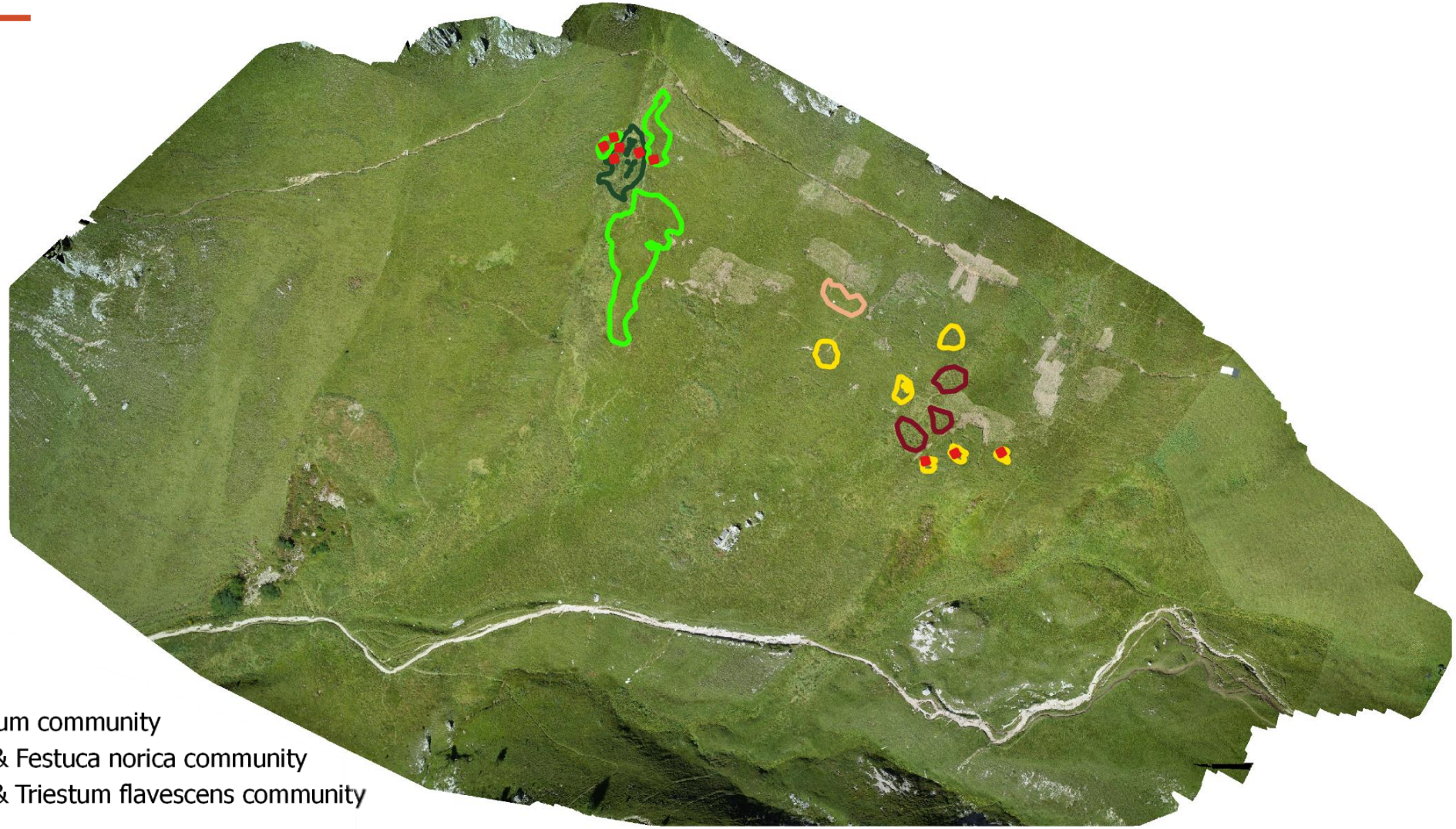


Workflow


Field
Lab
Botanical survey on the first field trip
Delineation of homogenous areas in high precision: **Vegetation classes for training**
Designation of the **quadrats**
Spectroradiometer measurements; Hyperspectral and High resolution RGB-photos of the quadrats
Vegetation analysis from the samples
Compilation of a species-level database
UAV flight RGB
UAV flight Hyperspectral
Create orthomosaic
PCA analysis
SVM classification
Validation by confusion matrix

Defined classes

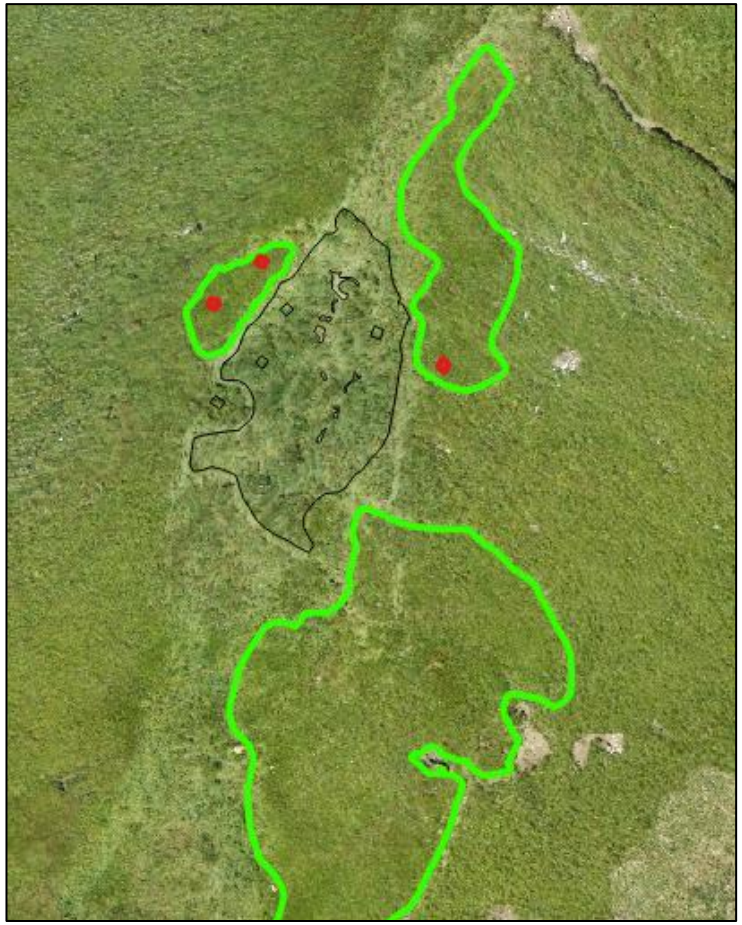
Funes valley study area – defined vegetation classes



Defined classes

- Based on the botanical survey on the first field trip

Class 01 – Anthoxanthum alpinum community

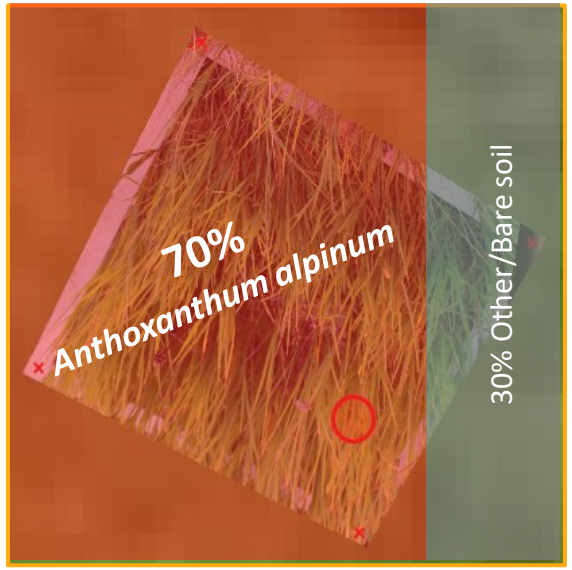


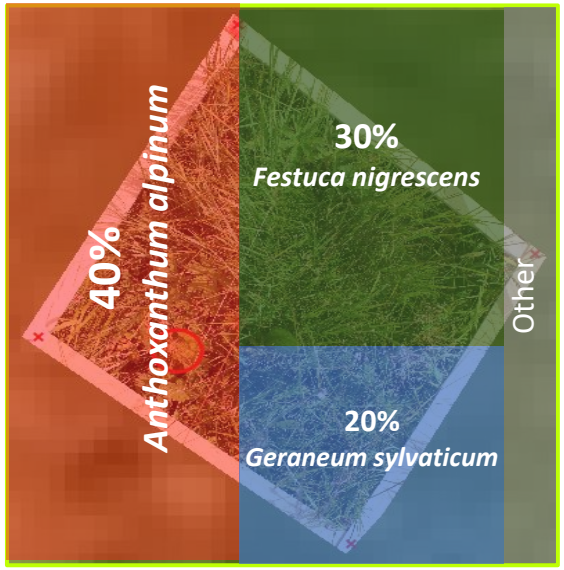
A very bright green and dense grass, in the surveyed plots, it is really homogenous. The areas were clearly defined on the ground and on the orthomosaic too.

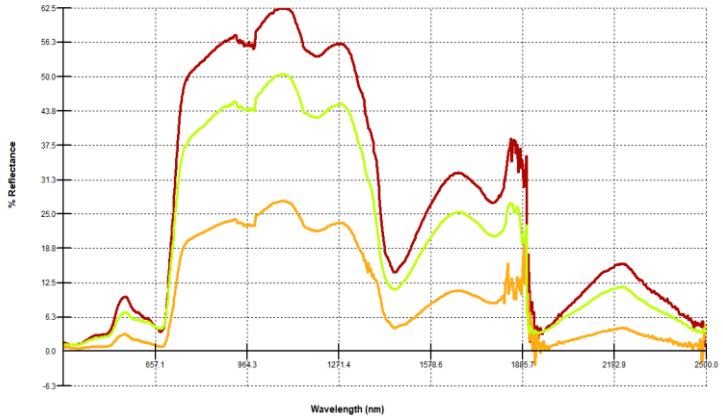
Anthoxantum alpinum	Grass
Phleum rhaeticum	Grass
Avenula pubescens	Grass
Festuca nigrescens	Grass
Geraneum sylvaticum	Forb
Knautia longifolia	Forb
Trollius europaeus	Forb
Achillea millefolium	Forb
Pulsatilla alpina	Forb
Carduus defloratus	Forb
Pimpinella major	Forb
Silene vulgaris	Forb
Carex sempervirens	Grass
Poa glauca	Grass
Hypericum maculatum	Forb

Defined classes

Class 01 – Anthoxanthum alpinum community







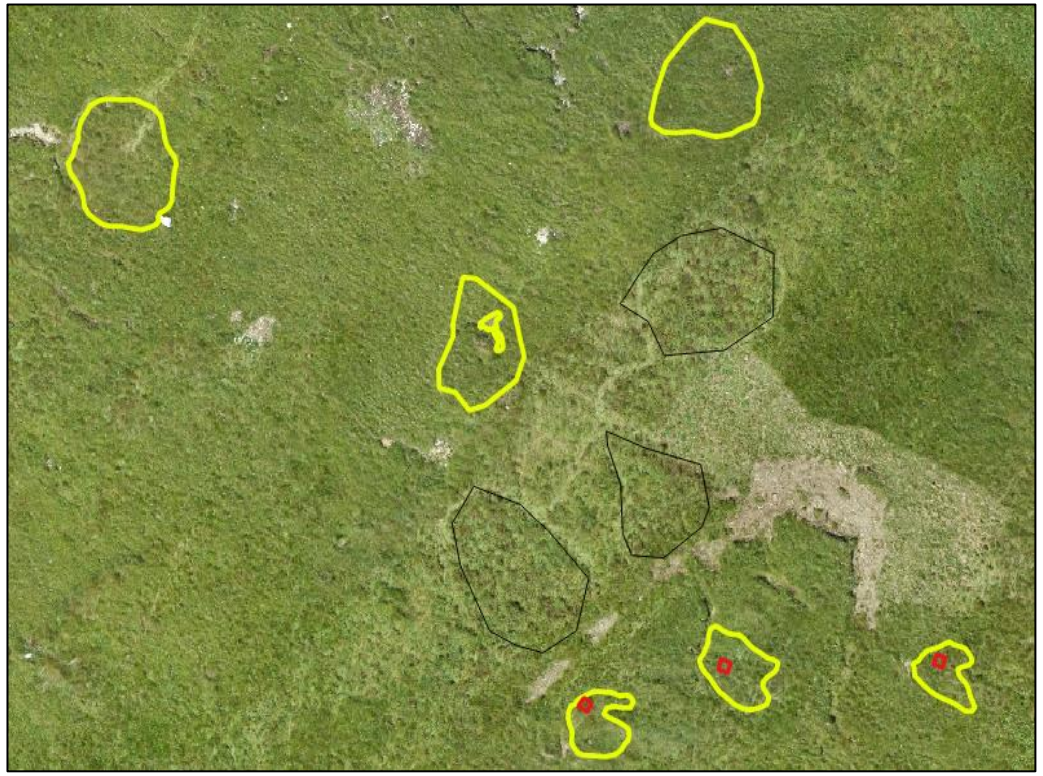
Spectral signals of the quadrats measured with the spectroradiometer

66% - Anthoxanthum alpinum

Phleum rhaeticum	Grass
Avenula pubescens	Grass
Festuca nigrescens	Grass
Geraneum sylvaticum	Forb
Knautia longifolia	Forb
Trollius europaeus	Forb
Achillea millefolium	Forb
Pulsatilla alpina	Forb
Carduus defloratus	Forb
Pimpinella major	Forb
Silene vulgaris	Forb
Carex sempervirens	Grass
Poa glauca	Grass
Hypericum maculatum	Forb

Class 02 – Avenula pubescens and Festuca norica community

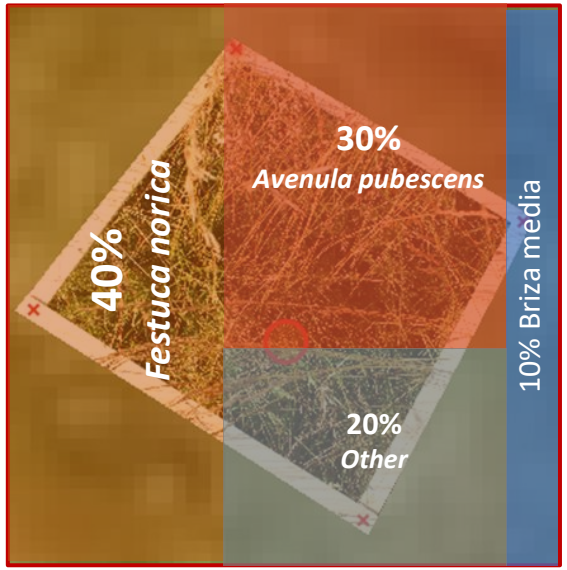
One of the most common species on the study site. This yellowish-green plants also occurs in all of the other classes, but are only in this area the dominant species.

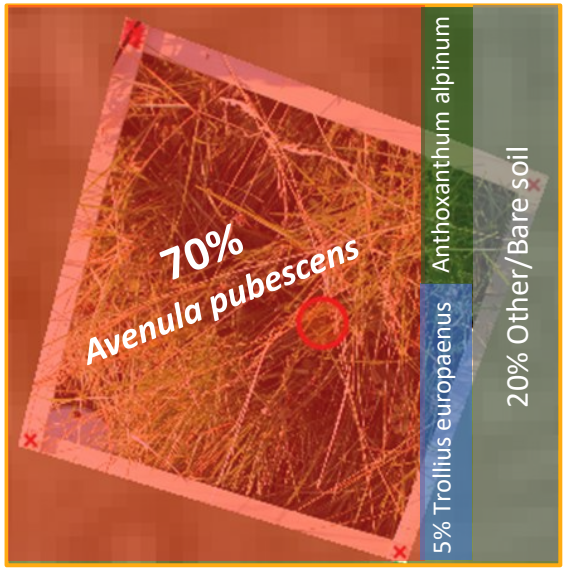


Avenula pubescens	Grass
Festuca norica	Grass
Avenula praeusta	Grass
Sesleria varia	Grass
Scabiosa lucida	Forb
Trollius europaeus	Forb
Arnica montana	Forb
Trifolium pratense	Legume
Carduus defloratus	Forb
Leontodon hispidus	Forb
Horminum pyrenaicum	Forb
Achillea millefolium	Forb
Pulmonaria australis	Forb
Briza media	Grass

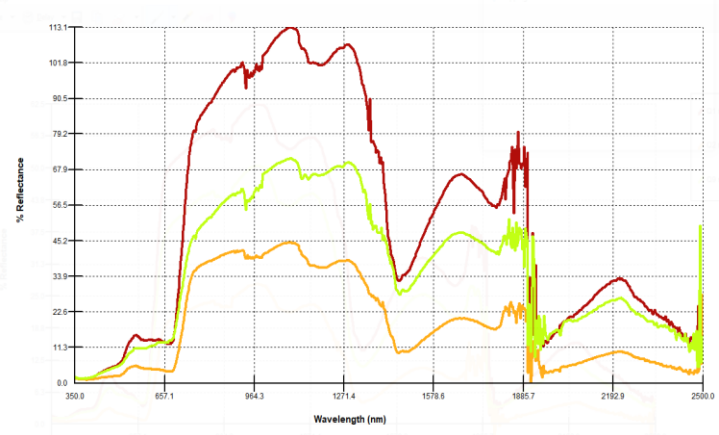
Defined classes

Class 02 – Avenula pubescens and Festuca norica community





No collected vegetation samples

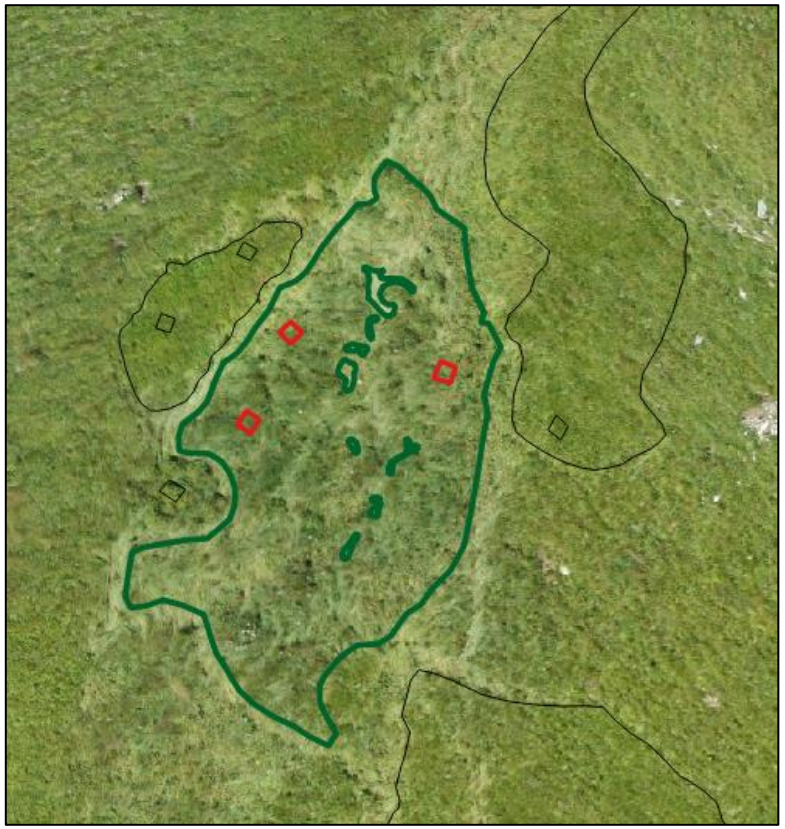


Spectral signals of the quadrats measured with the spectroradiometer

70% - Avenula pubescens & Festuca norica

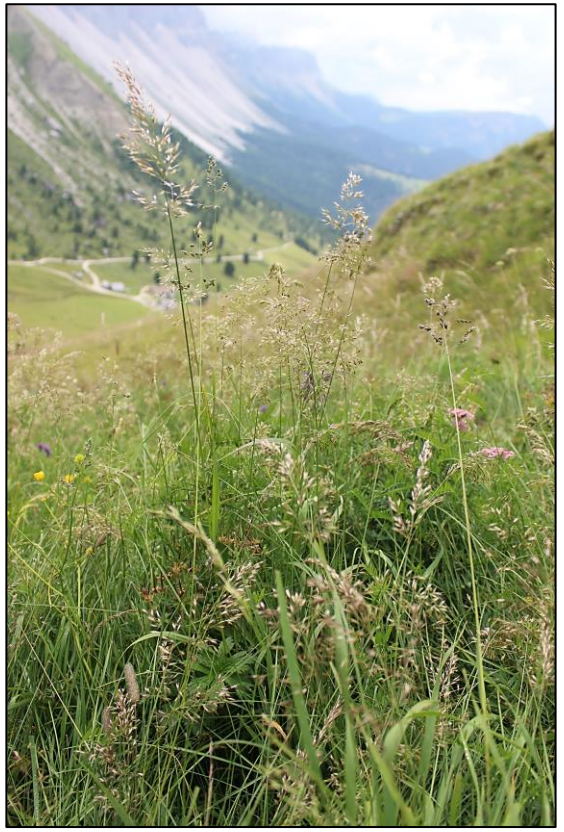
Avenula praeusta	Grass
Sesleria varia	Grass
Scabiosa lucida	Forb
Trollius europaeus	Forb
Arnica montana	Forb
Trifolium pratense	Legume
Carduus defloratus	Forb
Leontodon hispidus	Forb
Horminum pyrenaicum	Forb
Achillea millefolium	Forb
Pulmonaria australis	Forb
Briza media	Grass

Class 03 – Avenula pubescens and Trisetum flavescens community



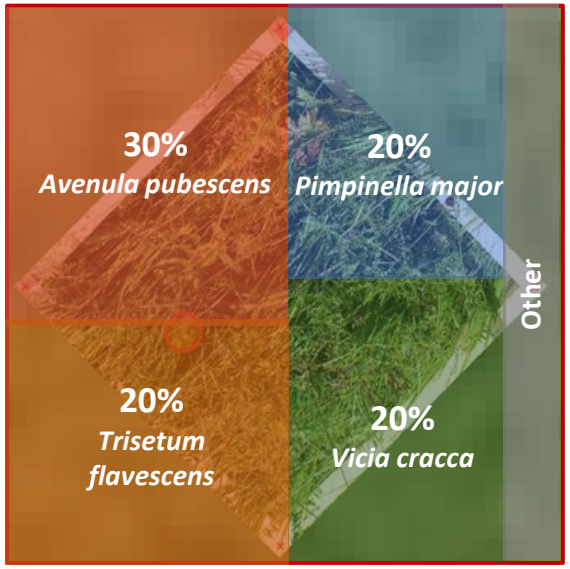
This community mostly occurs in the humid valley of the area, it is slightly darker than its surroundings.

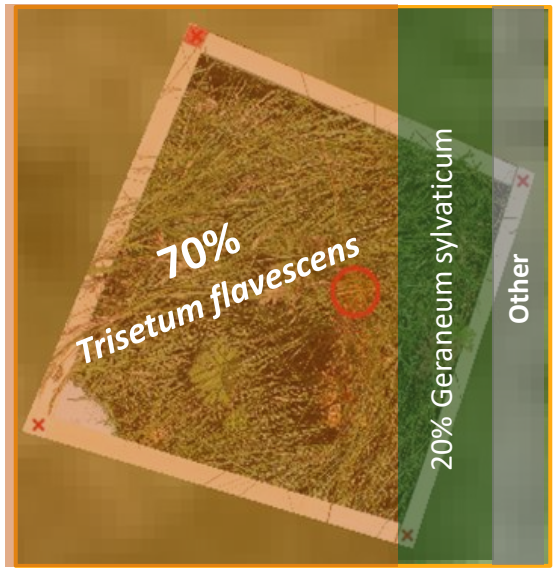
Trisetum flavescens	Grass
Avenula pubescens	Grass
Phleum rhaeticum	Grass
Achillea millefolium	Forb
Rumex alpestris	Forb
Geraneum sylvaticum	Forb
Knautia longifolia	Forb
Vicia cracca	Legume
Hypericum maculatum	Forb
Alchemilla hirsuta group	Forb
Trollius europaeus	Forb
Leontodon hispidus	Forb
Silene vulgaris	Forb
Pimpinella major	Forb

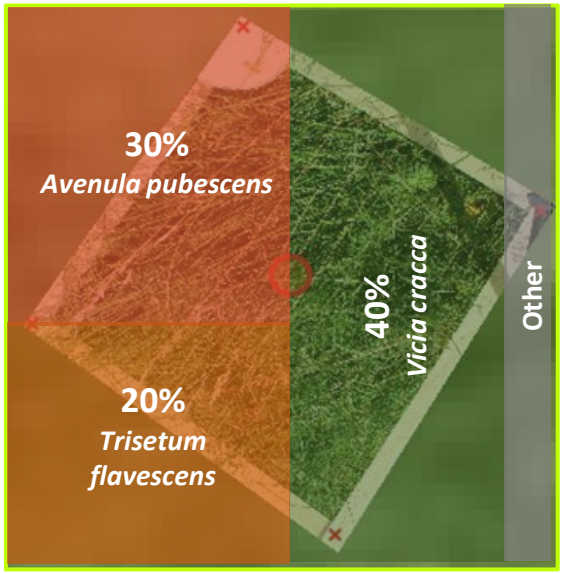


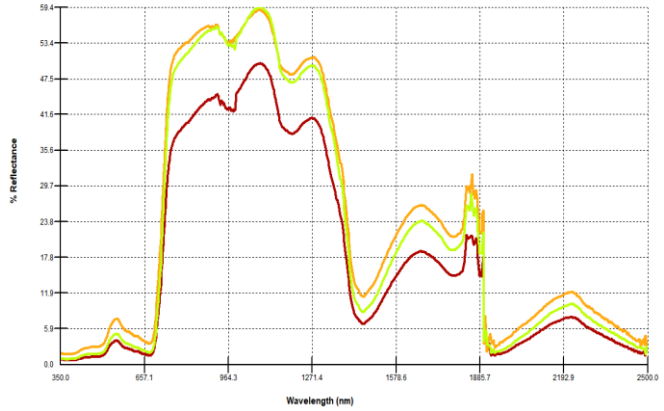
Defined classes

Class 03 – Avenula pubescens and Trisetum flavescens community









Spectral signals of the quadrats measured with the spectroradiometer

56% - Avenula pubescens & Triestum flavescens

Phleum rhaeticum	Grass
Achillea millefolium	Forb
Rumex alpestris	Forb
Geraneum sylvaticum	Forb
Knautia longifolia	Forb
Vicia cracca	Legume
Hypericum maculatum	Forb
Alchemilla hirsuta group	Forb
Trollius europaeus	Forb
Leontodon hispidus	Forb
Silene vulgaris	Forb
Pimpinella major	Forb

Class 04 – Short grass

Originally, we defined this as an independent vegetation class, but after a more detailed survey, we found these areas are homogenous because of anthropogenic influences. – No recorded quadrats because of this.

Trisetum flavescens	Grass
Carex sempervirens	Grass
Sesleria varia	Grass
Carex caryophyllea	Grass
Luzula alpina	Grass
Phyteuma orbiculare	Forb
Carduus defloratus	Forb
Hieracium morisianum	Forb
Scabiosa sp	Forb
Gentiana anisodonta	Forb
Aster bellidiastrum	Forb
Horminum pyrenaicum	Forb
Anthyllis vulneraria	Legume
Pedicularis elongata	Forb
Festuca norica	Grass
Polygonum viviparum	Forb

Class 05 – Geranium sylvaticum community

Rusty coloured in this season (September) – characteristic field pattern, occurs in a variety of locations in the whole study area.

No recorded quadrats

Geraneum sylvaticum	Forb
Avenula pubescens	Grass
Festuca norica	Grass
Alchemilla group hirsutae	Forb
Trifolium pratense	Legume
Trollius europaeus	Forb
Sesleria varia	Forb
Phleum rhaeticum	Grass
Silene vulgaris	Forb
Leontodon hispidus	Forb
Rumex alpestris	Forb
Achillea millefolium	Forb
Ranunculus nemorosus	Forb
Pulsatilla alpina	Forb

Other defined classes

Modified and non-vegetation classes:

- Sparse/replanted areas
  In some areas they replanted the vegetation, spectrally close to the bare soil because it is not dense enough to cover it
- Covered areas
  Same, but covered with textile and cut-of grass (Class 4)
- Wooden barriers
  Near the replanted areas to stop the erosion
- Drooped (or trampled) grass
  The areas where traces from a field survey two weeks earlier that were still visible
- Shadow
- Bare soil
- Bare rock

Σ **12 classes** (5 grassland communities + 7 „others”)

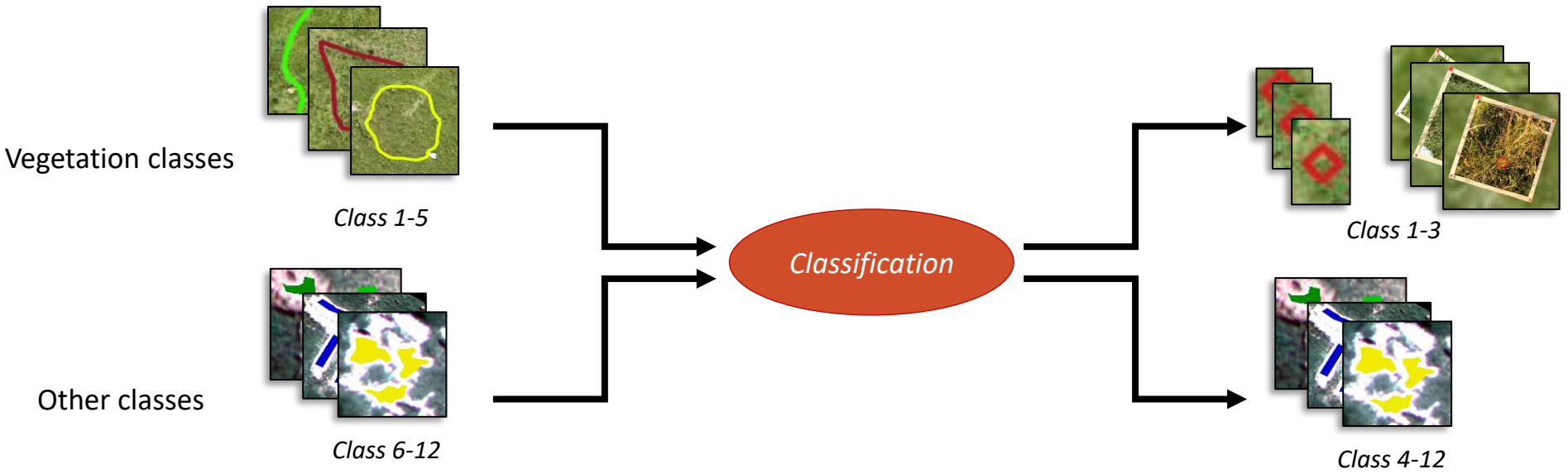
Classification

For training:

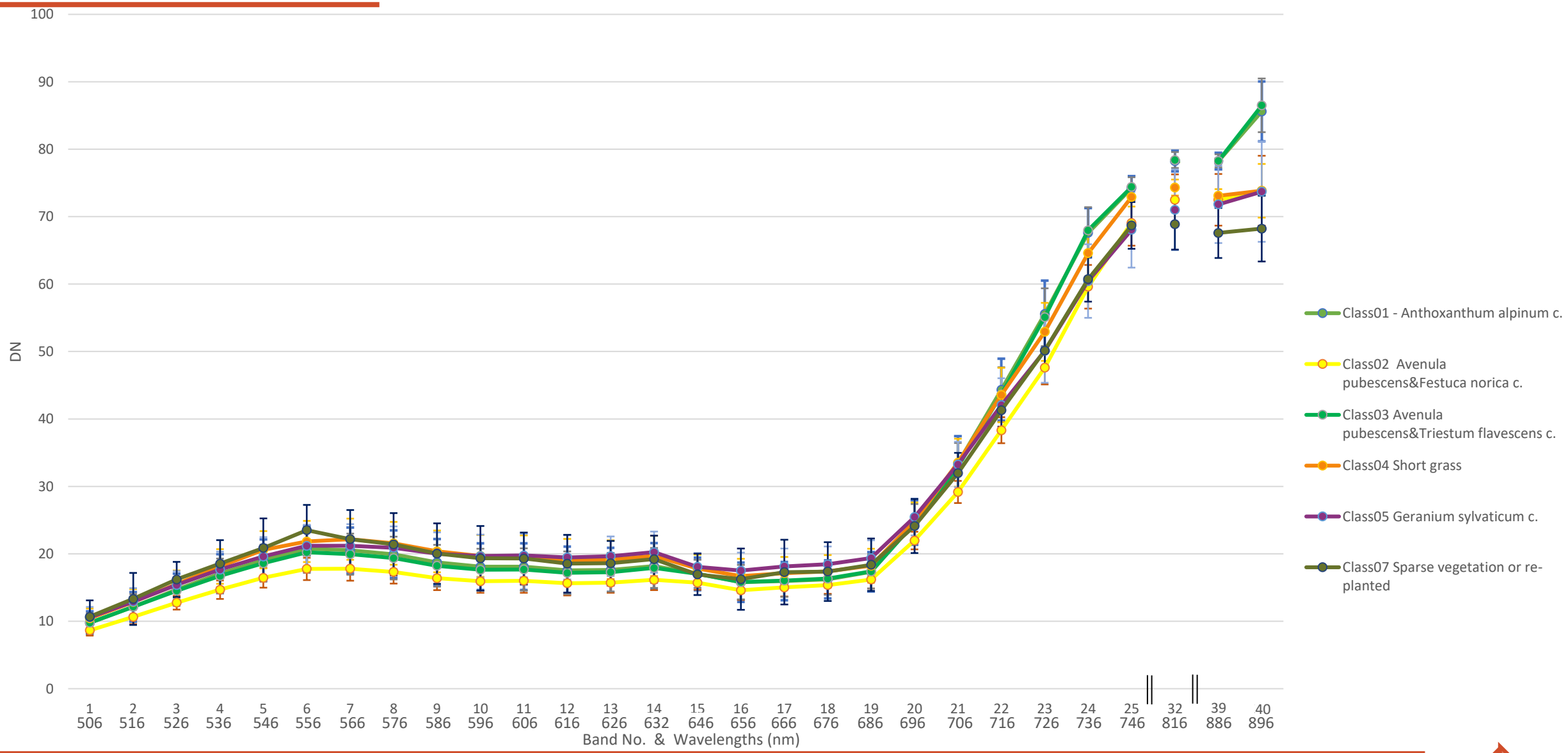
- Based on the botanical survey in the first field trip
- Smaller subsets of it based on the orthomosaic
- Delineated homogenous areas with high precision (GNSS RTK GPS)
- Non-vegetation classes based on orthomosaic – 2/3 for training

For validation:

- 50x50 cm quadrats - knowing the exact content of them
- Areas: approximately 350-400 pixels
- Corner points measured with high precision (GNSS RTK GPS)
- Non-vegetation classes based on orthomosaic – 1/3 for validation
- Validation with Confusion matrix



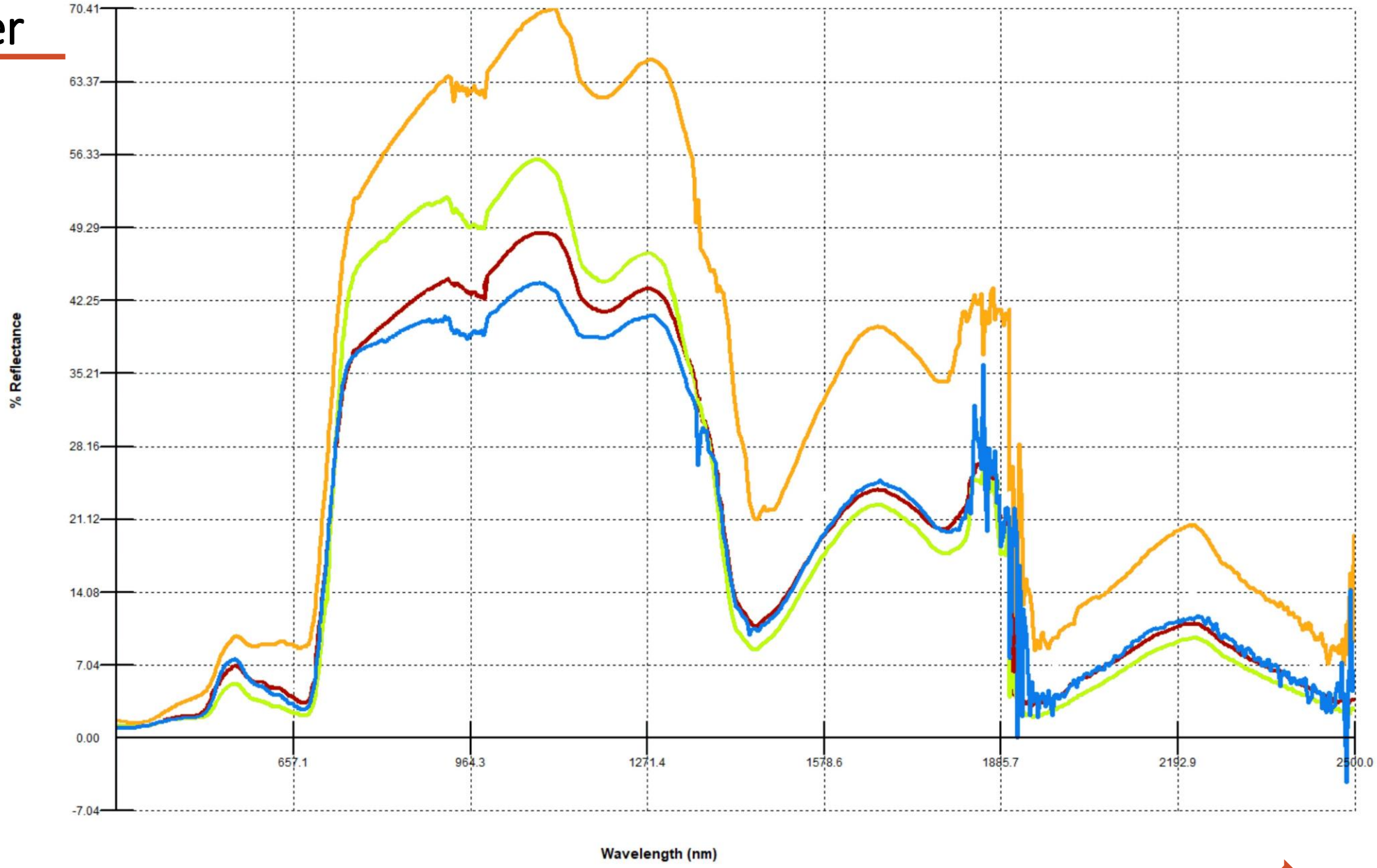
Challenges


100
90
80
70
60
50
40
30
20
10
0
DN
1 506
2 516
3 526
4 536
5 546
6 556
7 566
8 576
9 586
10 596
11 606
12 616
13 626
14 632
15 646
16 656
17 666
18 676
19 686
20 696
21 706
22 716
23 726
24 736
25 746
32 816
39 886
40 896
Band No. & Wavelengths (nm)
Class01 - Anthoxanthum alpinum c.
Class02 Avenula pubescens&Festuca norica c.
Class03 Avenula pubescens&Triestum flavescens c.
Class04 Short grass
Class05 Geranium sylvaticum c.
Class07 Sparse vegetation or re-planted

Spectroradiometer

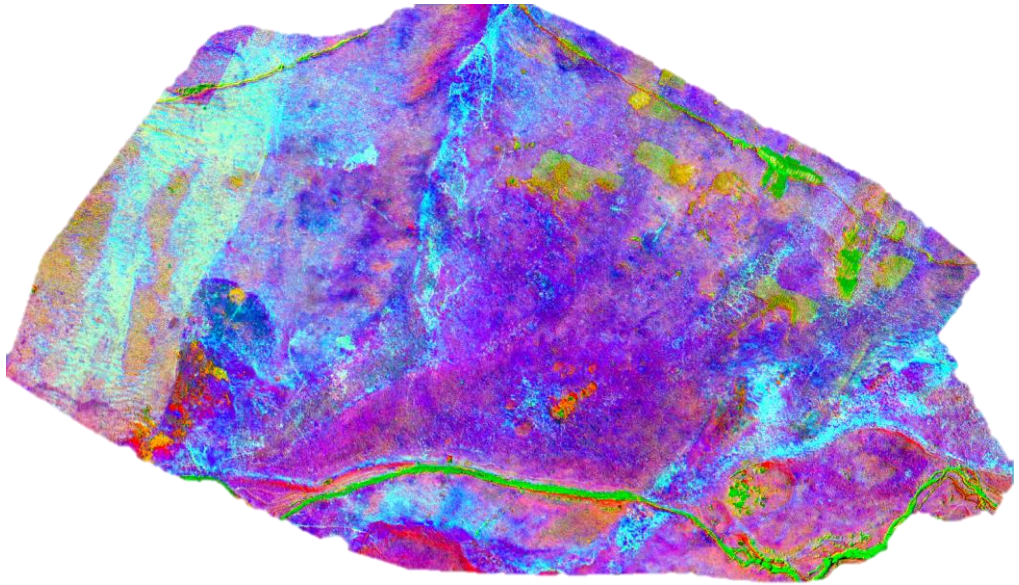
Legend

- Class 1 – *Anthoxanthum alpinum*
- Class 2 – *Avenula p.* & *Festuca norica*
- Class 3 – *Avenula p.* & *Trisetum flavescens*
- Sparse /Re-planted



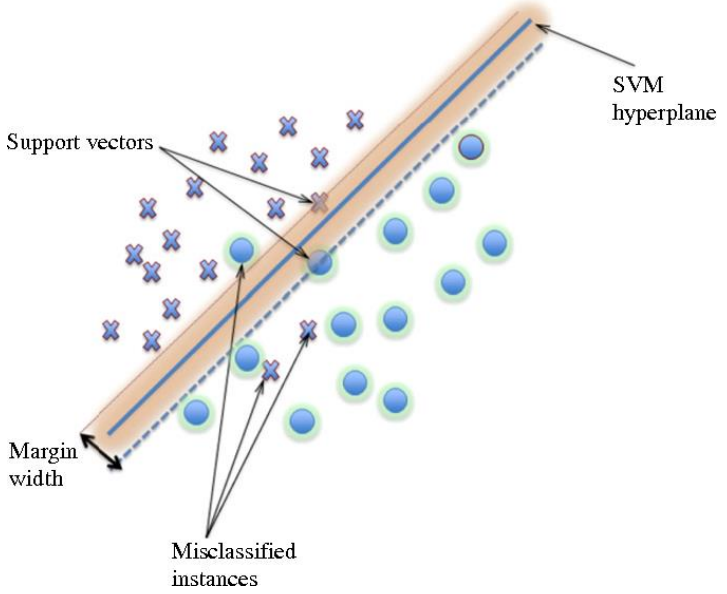
PCA – Principal Component Analysis

- Based on Eigenvalues we reduced the variables
- 28 bands reduced to **6 bands** which contains the majority of the information



Support Vector Machine classification

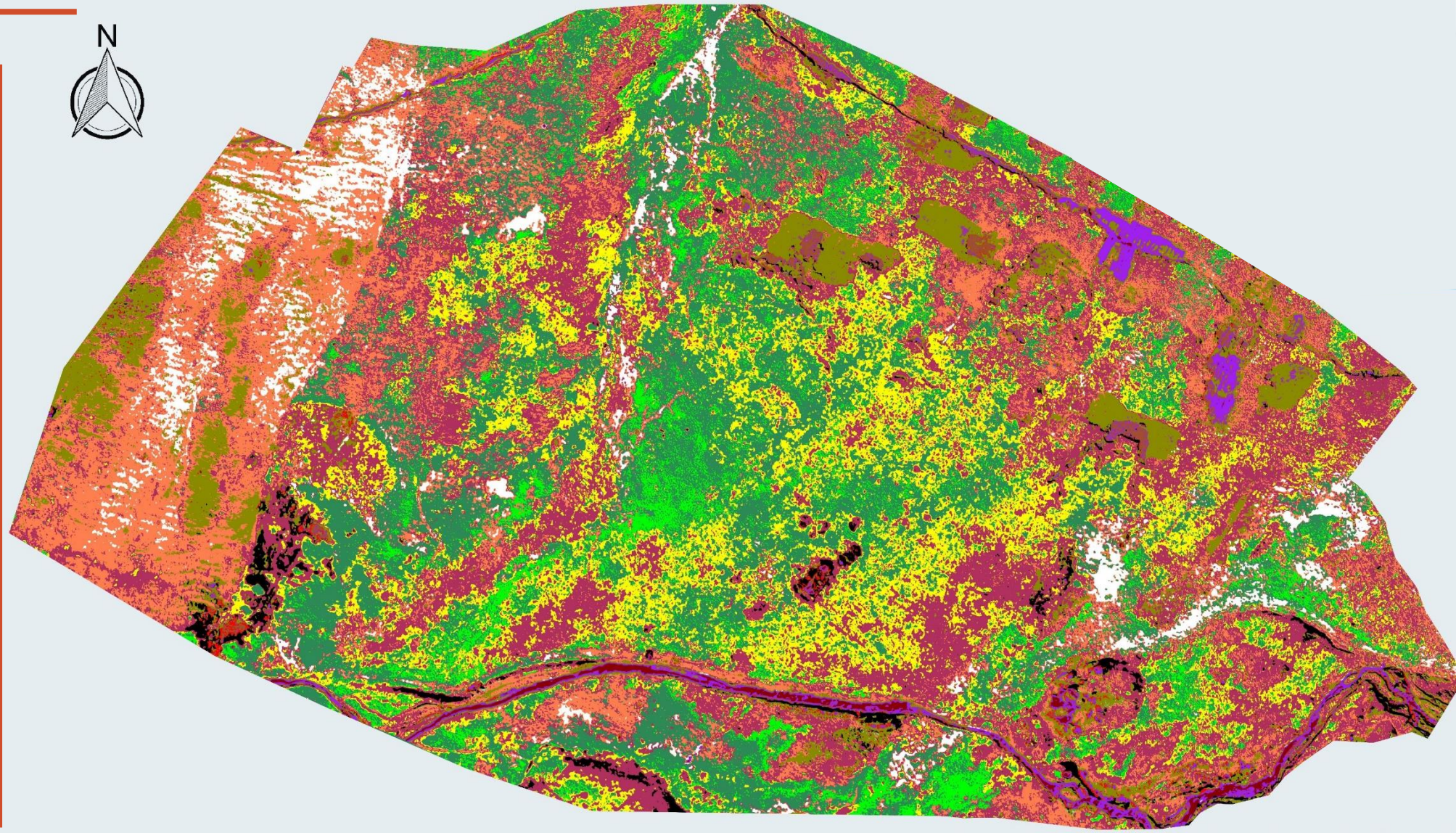
- A supervised learning method
- Try to find the proper hyperplanes in the spectral space between the classes
- Suitable for smaller datasets (e.g. not like ANN)
- We set the proper parameters based on one classification rule image (the probability of a given pixel belongs to that class)
- Used software: ENVI Classic 5.2



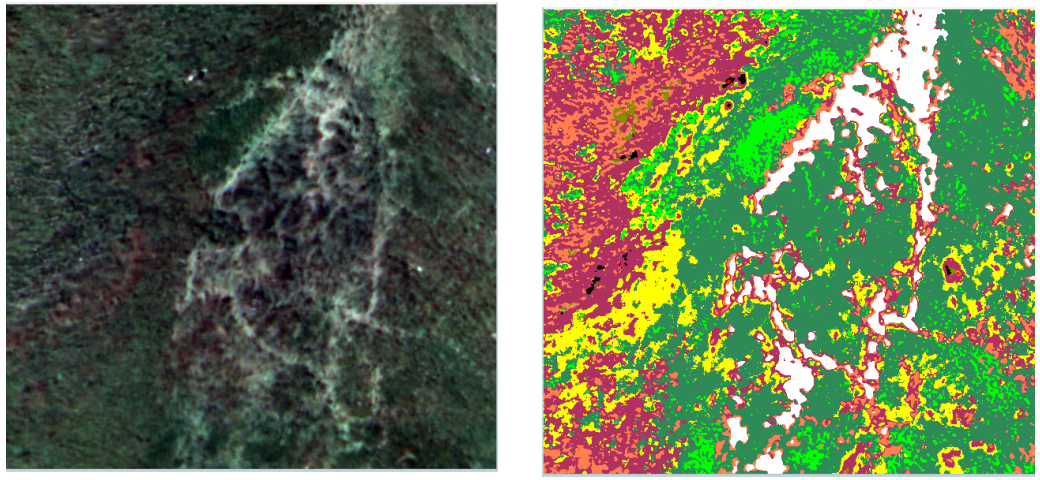
Source: G.Mountrakis et.al. (2010)

Result map

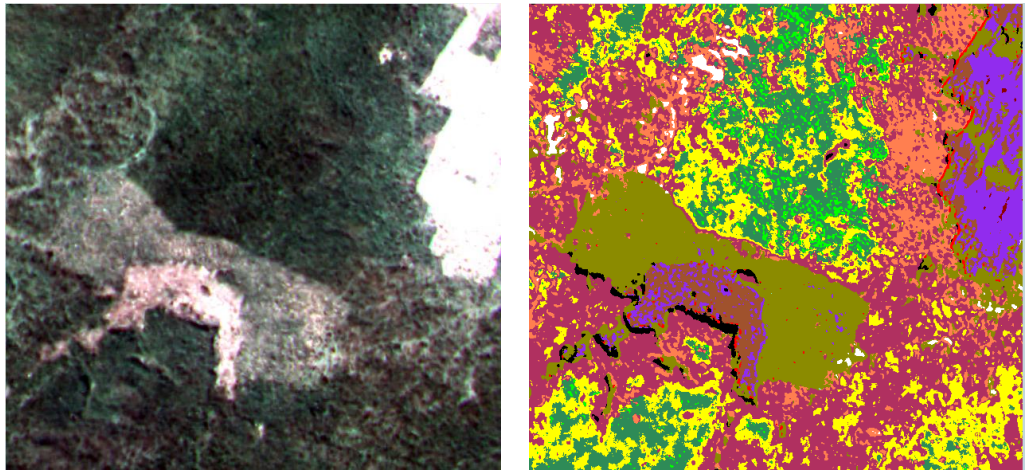
Support Vector Machine Classification of Funes Valley study area



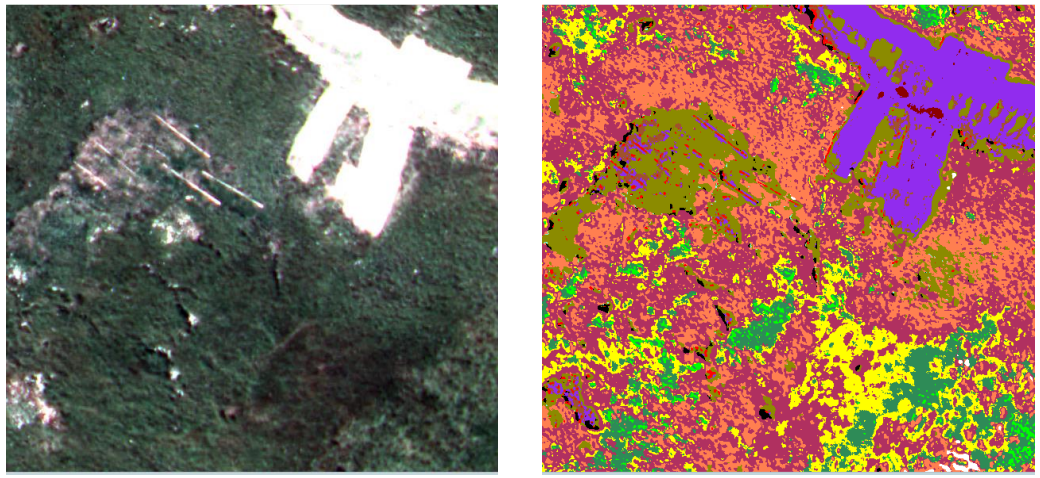
Examples



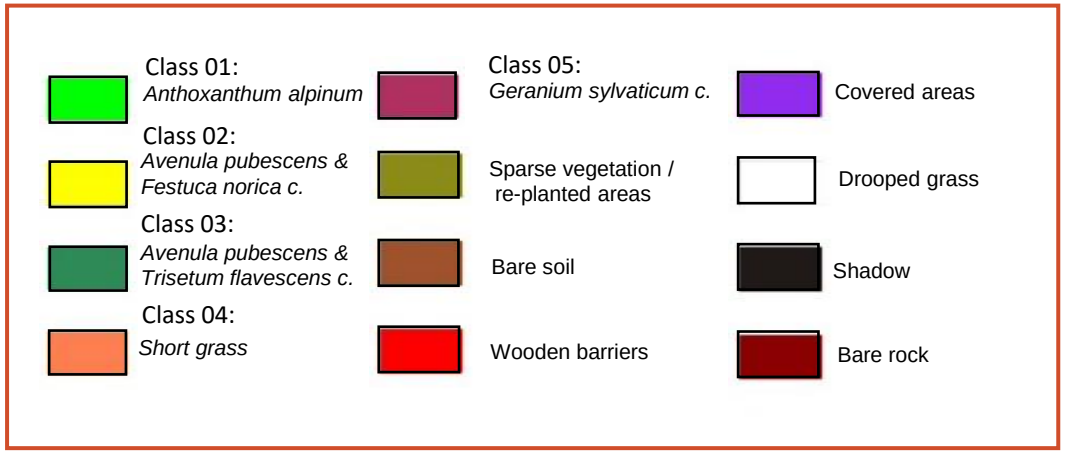
Humid Valley with Class 03 – Avenula pubescens and Trisetum flavescens community and drooped grass



A shallow erosion area with sparsen vegetation surrounded by Class 05: Geranium sylvaticum and a combination of the two Avenula pubescens classes (Class 02 and Class 03)



Shallow erosion areas (covered and replanted ones with the wooden barriers) – surrounded by Class 04: short grass and Class 05: Geranium sylvaticum



Results

Classes:	01	02	03	04	05
Achillea millefolium					
Alchemilla hirsuta group					
Anthoxanthum alpinum	66%	<5%			
Anthyllis vulneraria					
Arnica montana					
Aster bellidiastrum					
Avenula praeusta					
Avenula pubescens		50%	20%		
Briza media		<5%			
Carduus defloratus					
Carex caryophyllea					
Carex sempervirens					
Chaerophyllum hirsutum					
Festuca nigrescens	10%				
Festuca norica		20%			
Gentiana anisodonta					
Geraneum sylvaticum	7%		7%		
Hieracium morisianum					
Horminum pyrenaicum					
Hypericum maculatum					

Knautia longifolia					
Leontodon hispidus					
Luzula alpina					
Pedicularis elongata					
Phleum rhaeticum					
Phyteuma orbiculare					
Pimpinella major			7%		
Poa glauca					
Polygonum viviparum					
Pulmonaria australis					
Pulsatilla alpina					
Ranunculus nemorosus					
Rumex alpestris					
Scabiosa lucida					
Scabiosa sp					
Sesleria varia					
Silene vulgaris					
Trifolium pratense					
Trisetum flavescens			36%		
Trollius europaeus		<5%			
Vicia cracca			20%		

One of the dominant species

Occurs in the area but in minor

Does not occur in the area

% Percentage coverage inside the community (only if it is covered by a quadrat)

Validation

- The classified map – confusion matrix & the field expert

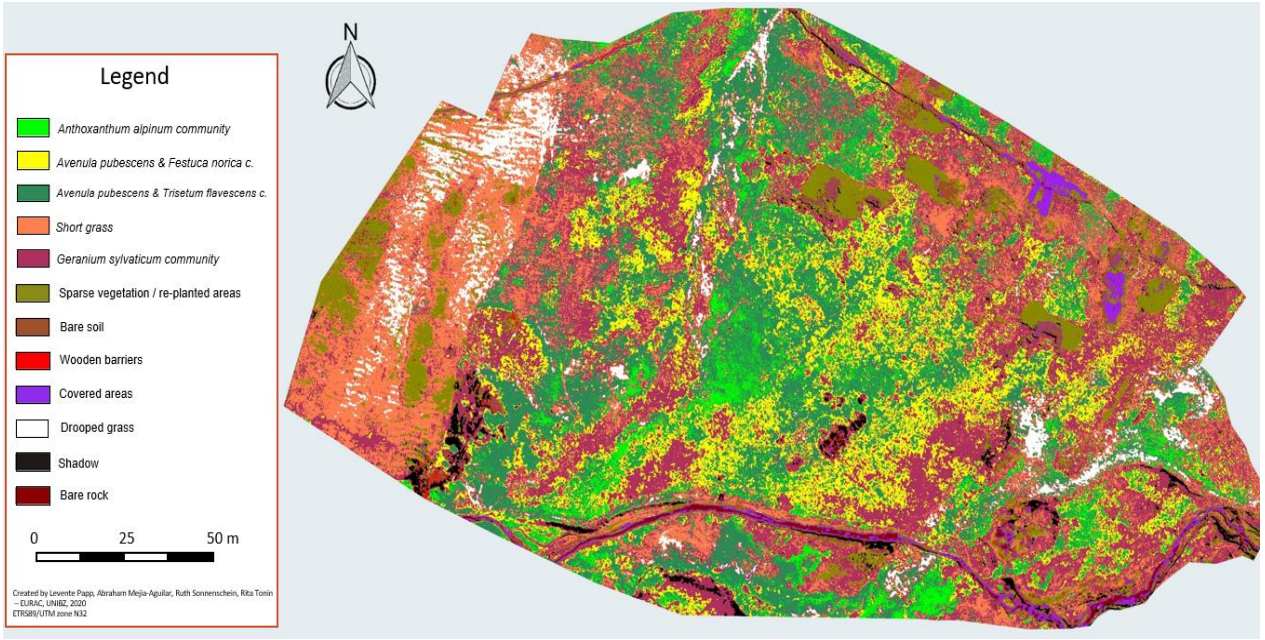
- Overrepresented/false positive results?
  - Small misclassification in case of class 2/3
  - Reasons: Species overlapping **Avenula pubescens** but they are two different communities
  - For the community of class 3: Avenula pubescens & Trisetum flavescens the time of the field measurements (September) quite late.
    The plants are starting yellowing during September and become similar to class 2.

- Geranium sylvaticum (Class 05) – beside of Avenula pubescens – Is the most common species, this community surrounding the other classes

- Class 4 (Short grass): Surrounding the shallow erosion plots and in the western cultivated areas - combined with drooped grass, classified as our result because the slope & anthropogenic influence

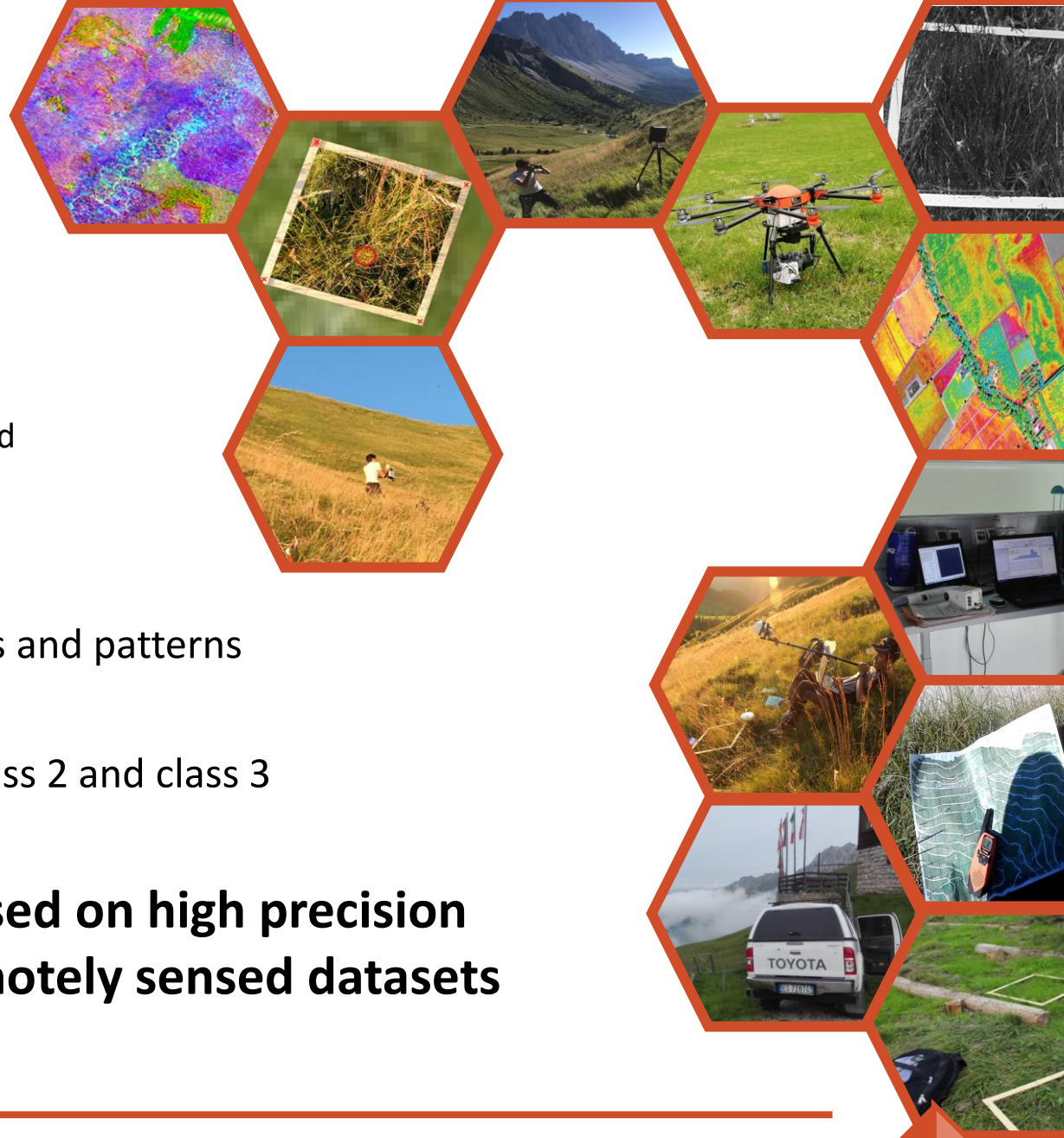
Overall Accuracy = (2001/2648) 75.5665%
Kappa Coefficient = 0.6785

Confusion matrix - Ground truth (percent)						
	Class 01	Class 02	Class 03	Class 04	Class 05	Total
Class01	61.61	0	0.78	0	0	7.33
Class02	0	32.19	0	0	2.88	5.29
Class03	38.39	35.36	89.3	0	0	22.47
Class04	0	1.06	7.83	80.15	3.69	30.97
Class05	0	31.4	2.09	19.85	93.43	33.95
Total	100	100	100	100	100	100



Discussion

- The major communities were delineated and investigated in two different scales
- A database was built up on species-level for the classes/communities
  - The dominant species and their coverage has been defined
- Hyperspectral aerial image was created and classified with high accuracy
- The classification represents the main field conditions and patterns
- Smaller misclassification on a minor area between class 2 and class 3 caused by the late investigation date



The grassland communities were mapped based on high precision ground measurements and hyperspectral remotely sensed datasets

Thank you for your attention!

Mapping of high-elevation alpine grassland communities based on hyperspectral UAV measurements

The research leading to these results has received funding from the Province of Bolzano under the Research and Innovation action, L§14 and from the European Regional Development Fund, Operational Program Investment for growth and jobs ERDF 2014-2020 under Project number ERDF1094, Data Platform and Sensing Technology for Environmental Sensing LAB-DPS4ESLAB.

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