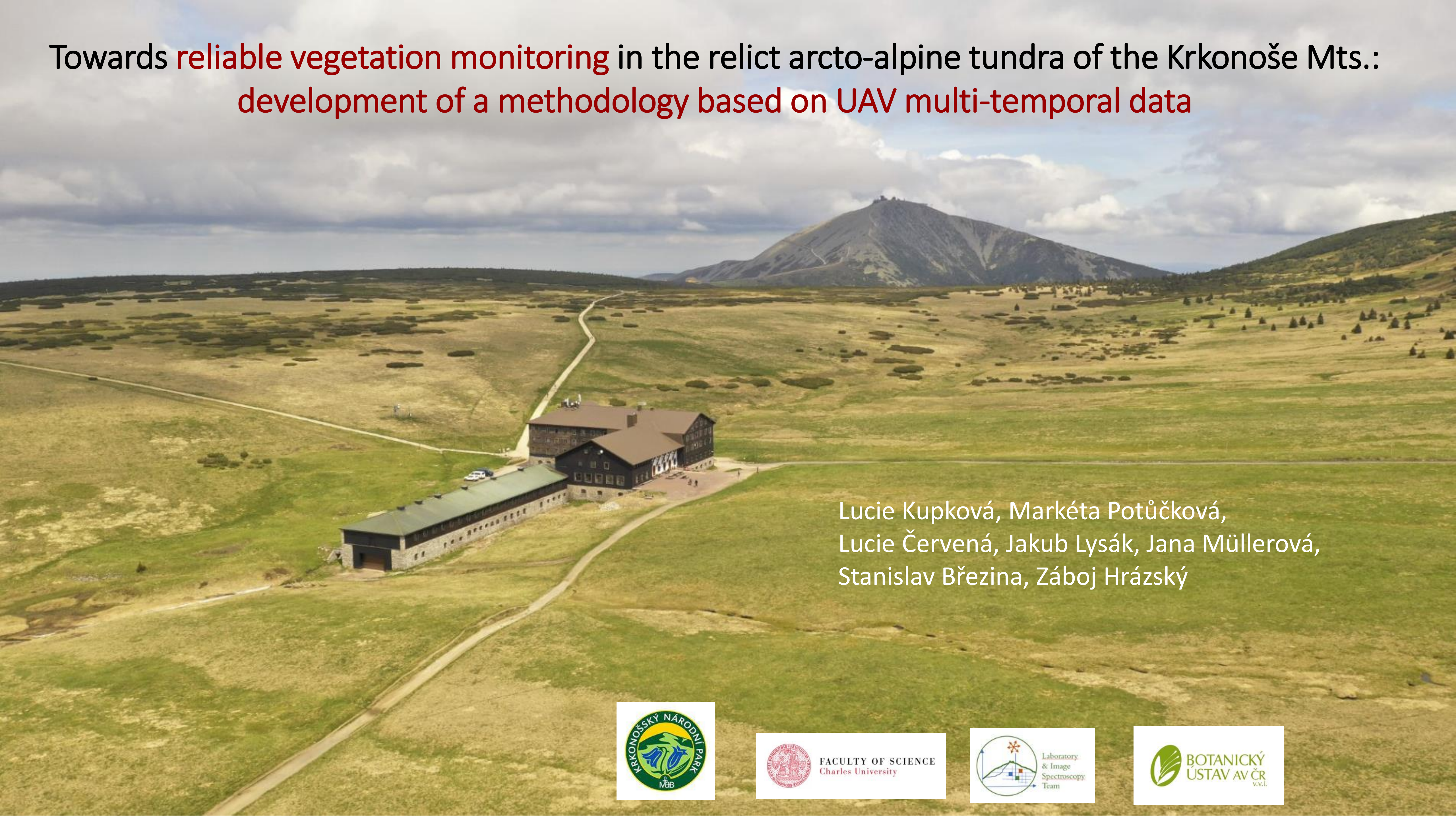
Towards reliable vegetation monitoring in the relict arcto-alpine tundra of the Krkonoše Mts.: development of a methodology based on UAV multi-temporal data



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KRKONOŠSKÝ NÁRODNÍ PARK
FACULTY OF SCIENCE Charles University
Laboratory & Image Spectroscopy Team
BOTANICKÝ ÚSTAV AV ČR v.v.i.

Project and Team

Operational program Environment: ***Development of methods for monitoring of the Krkonoše Mts. tundra vegetation changes using multispectral, hyperspectral and LIDAR sensors from UAV - drones (2019 –2023)***

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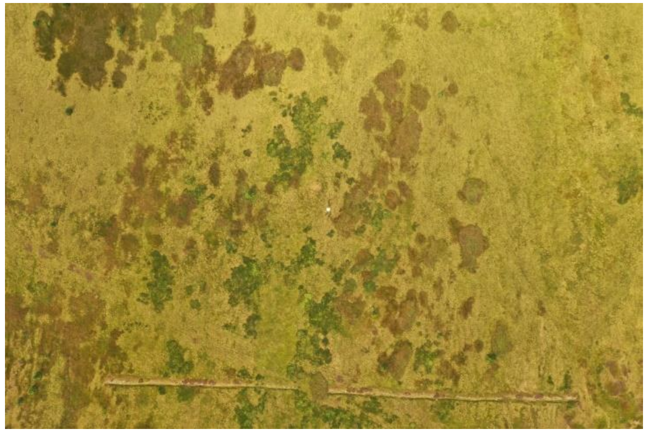
Project advisor – Clive Hurford (habitat monitoring specialist; a chair of the Eurosite Remote Sensing Support Group)

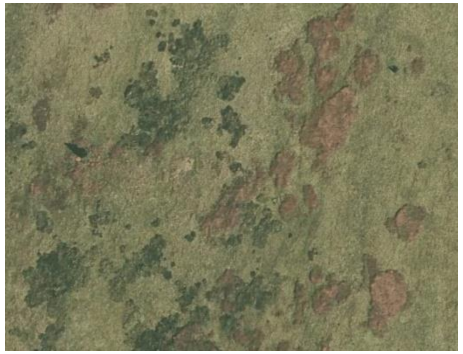
Starting points

- Tundra ecosystems (alpine treeless) belong to the most valuable natural phenomena worldwide
- Biotopes above the treeline are very sensitive to various types of environmental factors (… climatic change)
- Current problems addressed within the project:
  - Expansion of *Calamagrostis villosa, Molinia caerulea* and *Deschampsia caespitosa* into the *Nardus stricta* stands
  - Dwarf pine expansion
- Changes can be relatively fast in these areas and reliable monitoring is very important
- Earth observation – a potentially powerful tool for the monitoring (**objectiveness**, **repeatability**, **data from an extensive area in one moment**, **several times during season**…)
- Close collaboration of botanists and geoinformatics

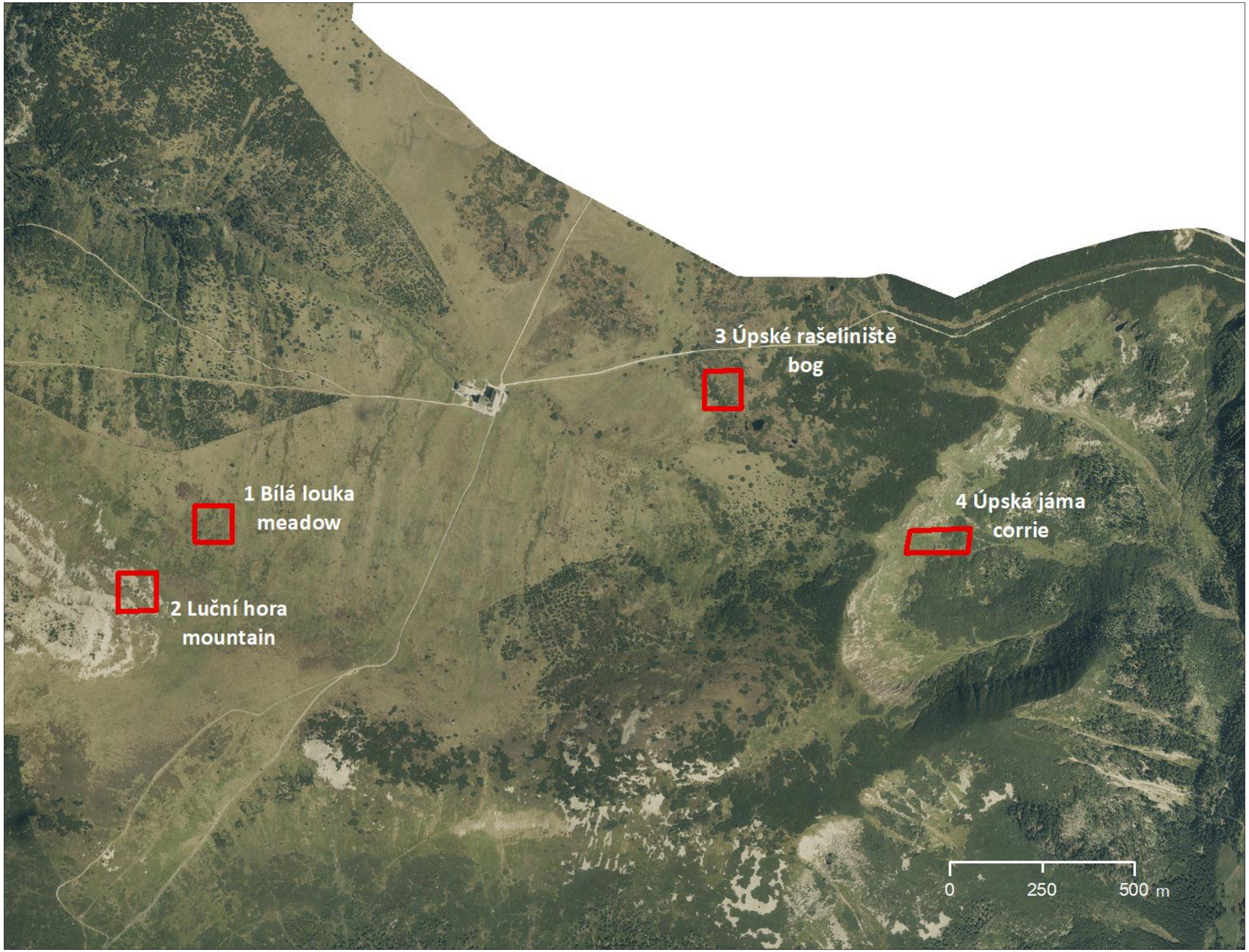


Goals

- To evaluate and compare potential (advantages vs. drawbacks) of different types of remote sensing data (multispectral, hyperspectral, LiDAR) for accurate mapping of tundra vegetation cover
- To test the accuracy of different classification methods (pixel and object-based) for different types of vegetation and different types of data.
- To monitor the changes over 5 years (seasonal, inter-annual) – implications for management (type of management vs. zone without human interference)
  - Detection of change… change vs. error of the used method
- **To propose a reliable methodology for tundra vegetation monitoring on the species level using RS** data from drone
- To implement the methodology in the NP monitoring practice



Study area – eastern tundra - research plots within the Eastern Tundra



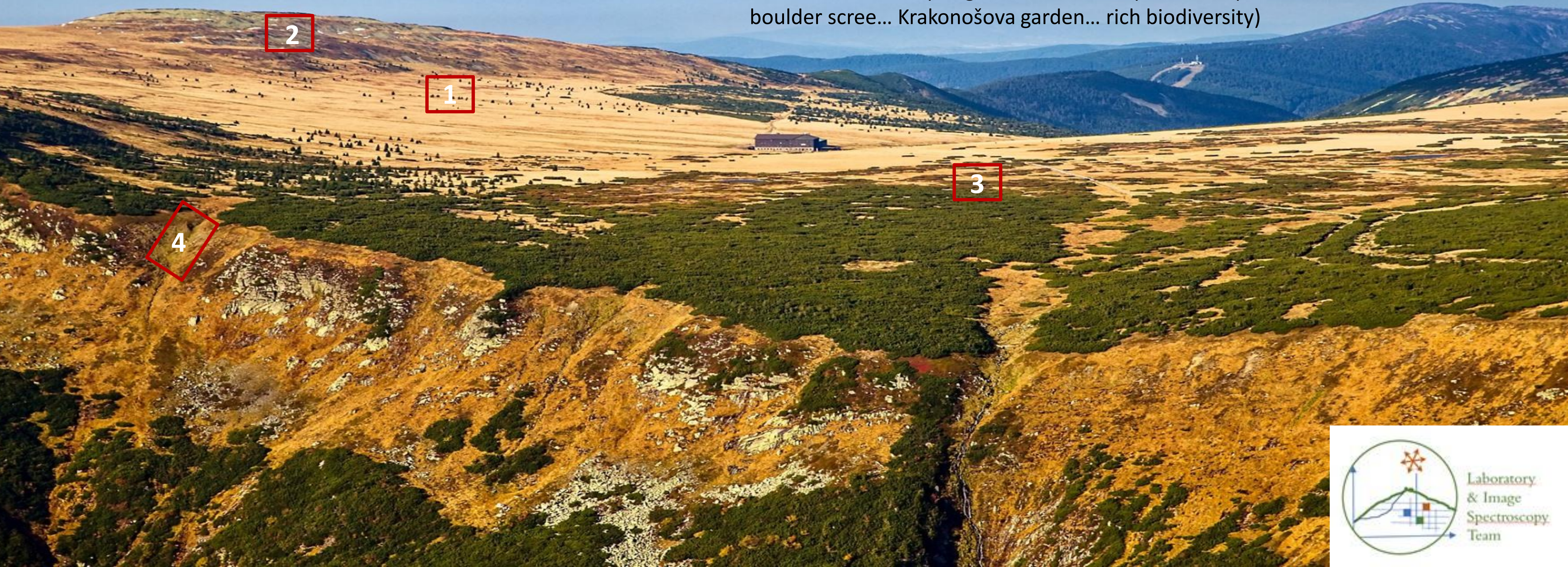
Research plots

1 Bílá louka meadow (acidophilous alpine grasslands, species poor stands dominated by matgrass – *Nardus stricta*, reedgrass – *Calamagrostis villosa* and purple moor-grass – *Molinia caerulea*, Norway Spruce - *Picea abies)*

2 Luční hora Mt. (fine grain mosaic dominated by wavy-hair grass - *Avenella flexuosa,* moss layer, close alpine grasslands, alpine heathlands, small shrubs, stone sea – boulder scree)

3 Úpské rašeliniště bog (boreal ombrotrophic raised bog, hummocks, moss layer and hollows, dwarf pine, grasses, lakes)

4 Kar Úpské jámy corrie (species rich subalpine tall grasses, Vaccinium heathlands, small springs, mosses, dwarf pine, subalpine deciduous shrubs, boulder scree… Krakonošova garden… rich biodiversity)



Laboratory & Image Spectroscopy Team

Research set-up

- Four research plots with different types of vegetation
- Each plot extent: 100 × 100 m
- Drone data acquisition: 4 times in the season (mid of June, July, August, September)
- Multispectral (MS), Hyperspectral (HS) and LiDAR data
- MS and HS data pixel size: 3 cm
- Spectral resolution:
  MS data 3/5/8 bands, HS data 270 bands
- Lidar data scanning density: ca 900 pts./m^2
- 4 years of field monitoring
- 5 years of methods testing and results evaluation/comparison

Used instruments

- **Drone: DJI Matrice 600 Pro** (price: 6,400 EUR)
- Gimbal Ronin (HS camera)
- IMU and GNSS (positional accuracy ca 5 m)

1. MS camera Micasense RedEdge – M®
Spectral bands: Blue, green, red, red edge, near-IR – **multispectral scanner (MSS)**

Price: 6,000 EUR

2. RGB camera Sony A7 ILCE-7 24,3 Mpx; lens- Voigtlander Color – Skopar 21 mm

Price: 920 EUR + 520 EUR

HS camera – Headwall Nano-Hyperspec®
(enables vegetation health evaluation)

- Pushbroom scanner
- 640 pixels
- lens 17 mm (possible also 12 mm a 23 mm)
- 270 bands (398,784 nm – 1 001,84 nm, spectral sampling 2,24 nm)
- Radiometric resolution: 12bit

Price: 40,000 EUR

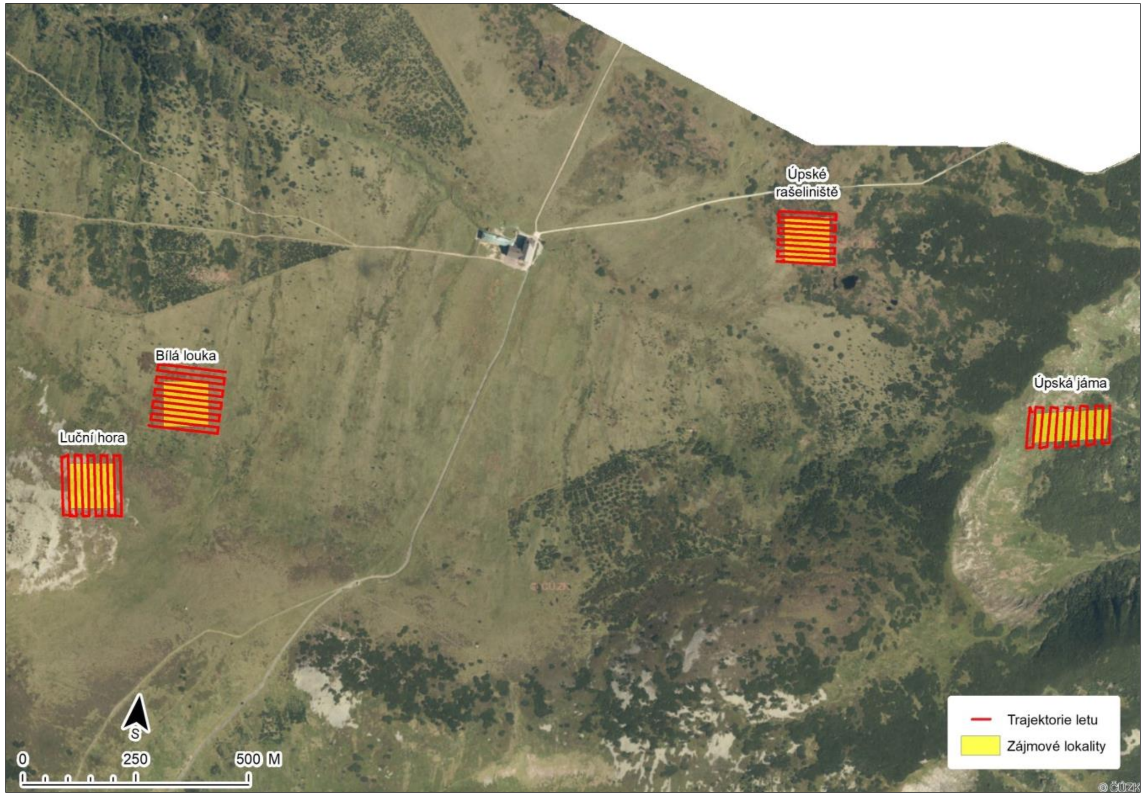
LiDAR RIEGL miniVUX-1UAV

- Compact & lightweight (1.55 kg / 3.4 lbs)
- 360° field of view
- Multiple target capability – up to 5 target echoes per laser shot
- Scan speed up to 100 scans/sec
- Measurement rate 100,000 measurements/sec

Price: 72,000 EUR

Used methods – UAV data acquisition

- Scanning from a height of about 50 - 60 m above the ground (constant for Luční hora, Bílá louka, Úpské rašeliniště)
- At the area kar Úpské jámy corrie a descending flight trajectory according to the terrain configuration (final altitude also about 50 m above the ground)
- Each area was flown sequentially in parallel flight lines
- forward overlap of 85% and sidelap 70%
- Calibration panels (ground control points – GCP) for radiometric calibration and geometric transformation used - black and white chessboard 30×30 cm, placed in the corners of the area and further 5 inside the plot (for HS data)



Flight trajectories

Calibration panel (GCP)

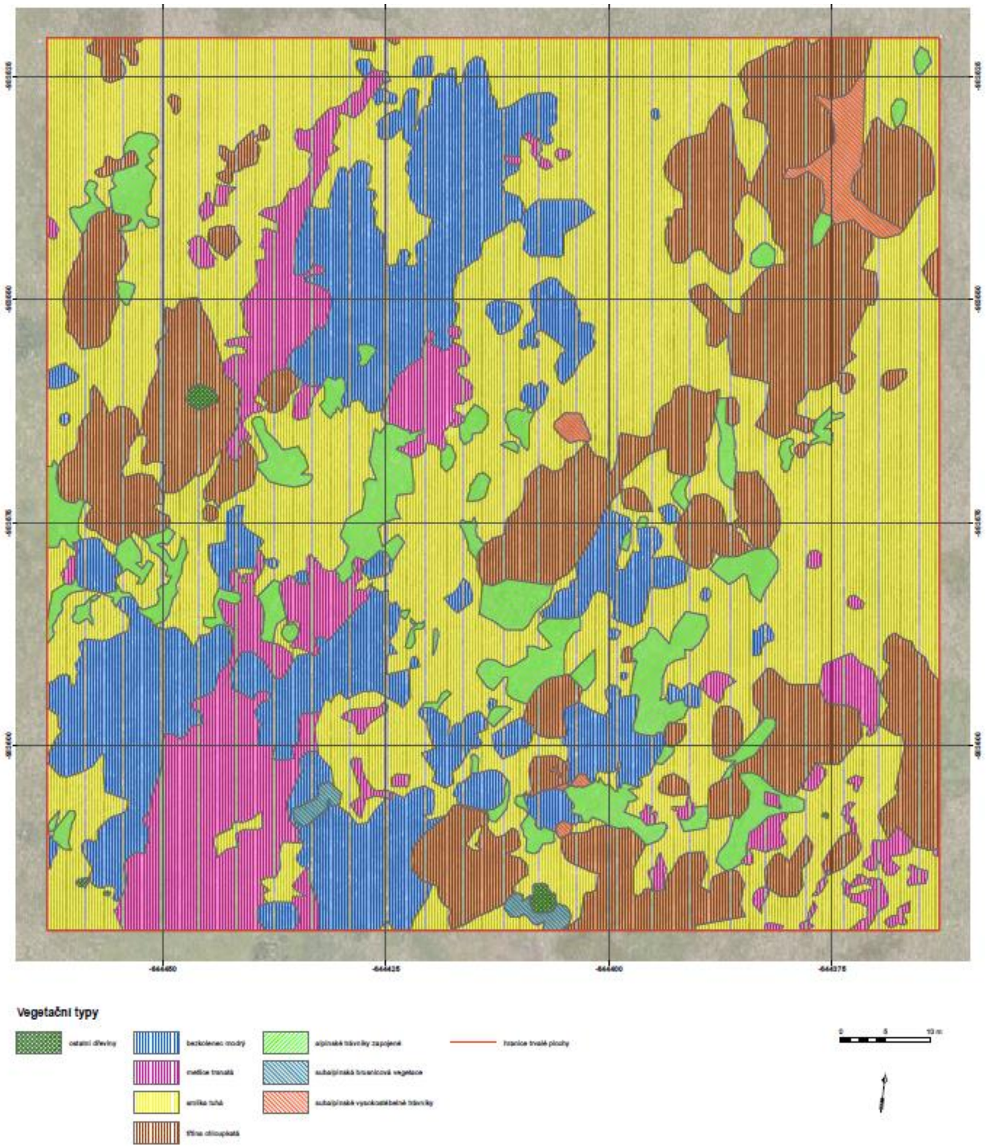
Used methods – field vegetation mapping

- Training and validation vegetation data collected by our colleagues from the Botanical Institute on the same dates as the data from the drones
- Trimble GeoExplorer GeoXH 6000 or Trimble GeoExplorer GeoXH 2008 GPS used
- Positional accuracy 1-5 cm
- Collector for ArcGIS with orthophoto from UAS (taken several days before the vegetation data collection)
- Record a point in the center of vegetation patch and create a buffer around it
- Manual correction of the collected polygons position in GIS based on the orthophoto (small polygons not used in case of uncertain localization)

Outputs:

1. Classification legend (two levels: general – 15 categories, detailed – 50 categories)
2. Training and validation polygons (882 polygons – ca 1/3 for used for training and 2/3 for validation, total area 5901 m^2)
3. Vegetation map for each area

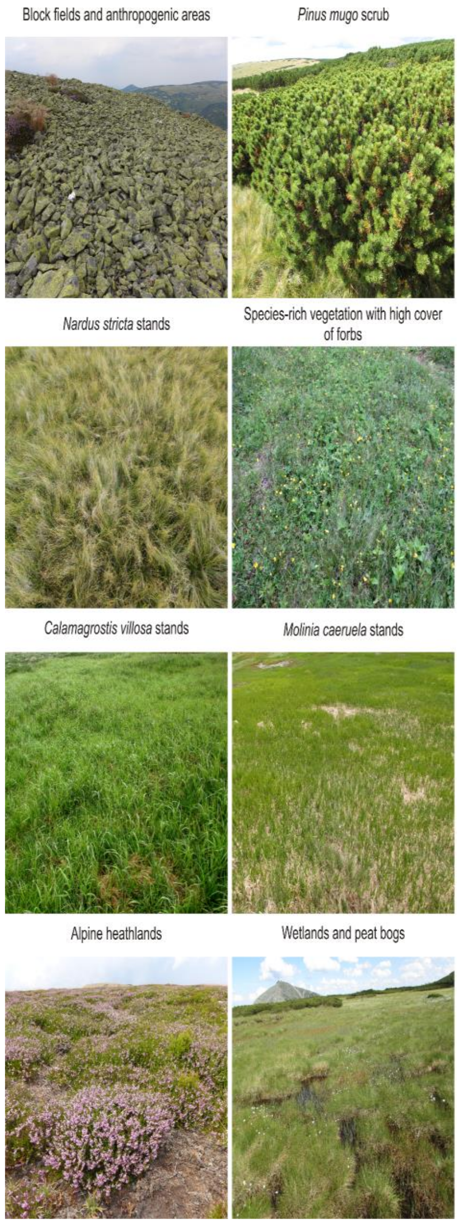
Vegetation map for Bílá louka meadow plot



Classification legend

Typ	Description
1	Boulder scree and artificial surfaces
2	Norway spruce stands
3	dwarf pine
4	subalpine Vaccinium vegetation
5	closed subalpine grasslands
5a	Nardus stricta
5b	species rich stands with abundance of dicots
6	subalpine tall grasslands
6a	Calamagrostis villosa
6b	Molinia caerulea
6c	Deschampsia cespitosa
7	subalpine tall-forb grasslands
8	alpine heathlands
9	wetlands and mires
10	open water
11	wind-exposed alpine grasslands
12	individuals or small groups of trees

typ	**Description**
af	stands dominated by Avenella flexuosa, minimal cover of other species (mainly Anthoxanthum alpinum, Cx bigelowii and herbs up do 10%)
afs	stands dominated by Avenella flexuosa, high cover of other species (mainly Anthoxanthum alpinum, Cx bigelowii and herbs)
bahno	histosol, dry peatland water holes
bet	individual or a group of Betula sp.
bor	Vaccinium myrtillus stand, shrubby vegetation
brus	Vaccinium vitis-idaea stand, shrubby vegetace
ca	stand dominated by Calamagrostis arundinacea, minimal cover of other species (up to 10%)
cetr	Cetraria islandica stand
cv	stand dominated by Calamagrostis villosa, minimal cover of other species (up to 10%)
cxbig	stand dominated by Carex bigelowii
cxlim	Carex limosa stand with histosol
desch	stand dominated by Deschampsia cespitosa, minimal cover of other species (up to 10%)
erang	stand dominated by Eriophorum angustifolium with histosol
ervag	stand dominated by Eriophorum vaginatum
hup	Huperzia selago stand
jerab	individual or a group of Sorbus aucuparia
junc	stand dominated by Juncus filiformis, minimal cover of other species (up to 10%)
klec	Pinus mugo stand
klen	individual or a group of Acer pseudoplatanus
lis	lichens (mainly Cladonia sp.)
listnace	deciduous trees, see description for details
luz	Luzula luzuloides stand
mech	mosses
mokvskal	wet outcrops covered by mosses
mol	stand dominated by Molinia caerulea, minimal cover of other species (up to 10%)
nard	stand dominated by Nardus stricta, minimal cover of other species (up to 10%)
niva	tall-forb vegetation
ras	Sphagnum sp. stand
rostr	stand dominated by Carex rostrata with histosol
scirp	stand dominated by Scirpus sylvaticus
skala	rock outcrop
smrk	individual or a group of Picea abies
sut	blosckfields, mostly bare, with lichens
ten	fine grain mosaic of Trichophorum cespitosum, Eriophorum vaginatum and Nardus stricta
trich	stand dominated by Trichophorum cespitosum, minimal cover of other species (up to 10%)
vaculig	Vaccinium uliginosum stand, shrubby vegetation
voda	water
vrba	individual or a group of Salix sp.
vres	Calluna vulgaris stand, shrubby vegetation
vyfuk	mosaic of rocks, bare soil, mosses and vegetation, wind-exposed alpine grassland
smes	see detail description
pram	vegetation of subalpine springs
sw	Swertia perennis stand, vegetation of subalpine springs
rasros	stand of Sphagnum sp. with significant cover of Drosera rotundifolia



Used methods – classification of vegetation

- Data prepocessing (radiometric, geometric)
- Resampling: pixel size 9 cm, HS data: 54 bands
- Detailed legend according to the categories present in individual areas
- Supervised classification using field training vegetation data

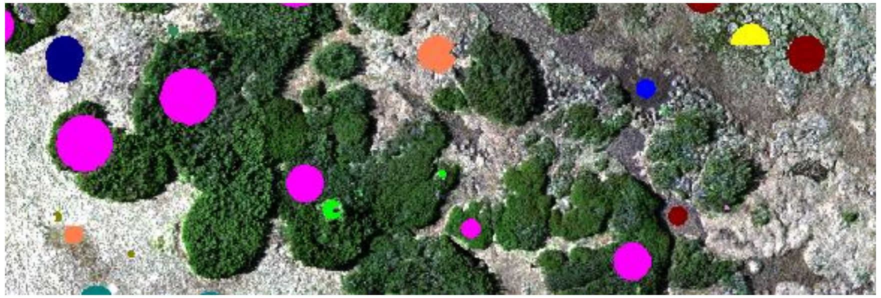
MS (from both cameras RGB, MSS; RGBMS = RGB+MSS) and HS data the same methods:

1. Pixel based methods: Maximum likelihood - MLC, Support Vector Machine - SVM (SW ENVI and ArcGIS), Random Forest - RF (SW R or ArcGIS)
2. Object based classification - OBIA: Support Vector Machine or Random forest classifier (SW ENVI or e-Cognition)

- Images from each date and data type classified (1) separately and also (2) in **multitemporal composite** = images (all bands) from all dates were merged and classified as one image (32 bands for RGBMS data and 216 bands for HS data for each research plot),
- Various multitemopral combinations

Classification legend for individual areas

Bílá louka meadow	**Luční hora Mt.**	**Úpské rašeliniště bog**	**Kar Úpské jámy - corrie**
afs	af	bare soil/mud	bor
cv	afs	cxlim	ca
cxbig	bor	erang	desch
desch	desch	ervag	erang
mol	Dwarf pine	junc	dwarf pine
nard	lis	dwarf pine	list
Picea abies	nard	mol	mokvskal
	blockfields	nard	mol
	Calluna vulgaris	rostr	nard
	vyfuk	*Picea abies*	niva
		ten	pram
		trich	pramsw
		trichcesp	rasrost
		vaculig	scirp
		water	*Picea abies*
		Calluna vulgaris	blockfields
			Calluna vulgaris



Used methods – accuracy assessment

- Training and validation data collected in the field – polygons:
  - 1/3 used for training and 2/3 for validation (802 polygons, total area 5,901 m^2)
- Random sample points generated within the validation polygons stratified according the summarized area of training + validation data
- Number of validation points for each mosaic: 3,393 (calculated based on reliability of validation accuracy on 2% level (Foody, G.M. Sample size determination for image classification accuracy assessment and comparison. *Int. J. Remote Sens.* 2009, *30*, 5273–5291)
- Minimal number of points for 1 category: 50
- Points generated in the center of pixels
- Minimal distance between the points: 13 cm (no points were generated in neighboring pixels)

- Standard methods for classification accuracy assessment used:
  - **Overall accuracy (OA)** – share of correctly classified pixels on the total number of pixels
  - Kappa index – compares the result of the classification with the classification created by a random process of classifying pixels into individual classes, 1 means a perfect match and 0 represents a purely random result

  Measures for **individual categories accuracy evaluation**
  - Producer's accuracy (PA) – the probability that a reference class is classified correctly
  - User's accuracy (UA) – the probability that a pixel in the classification actually represents this reference (field) class

  (Jensen, R.H. Introductory Digital Image Processing. A Remote Sensing Perspective. 2005, Pearson Prentice Hall)

Results – Competitive species – seasonal changes in phenology

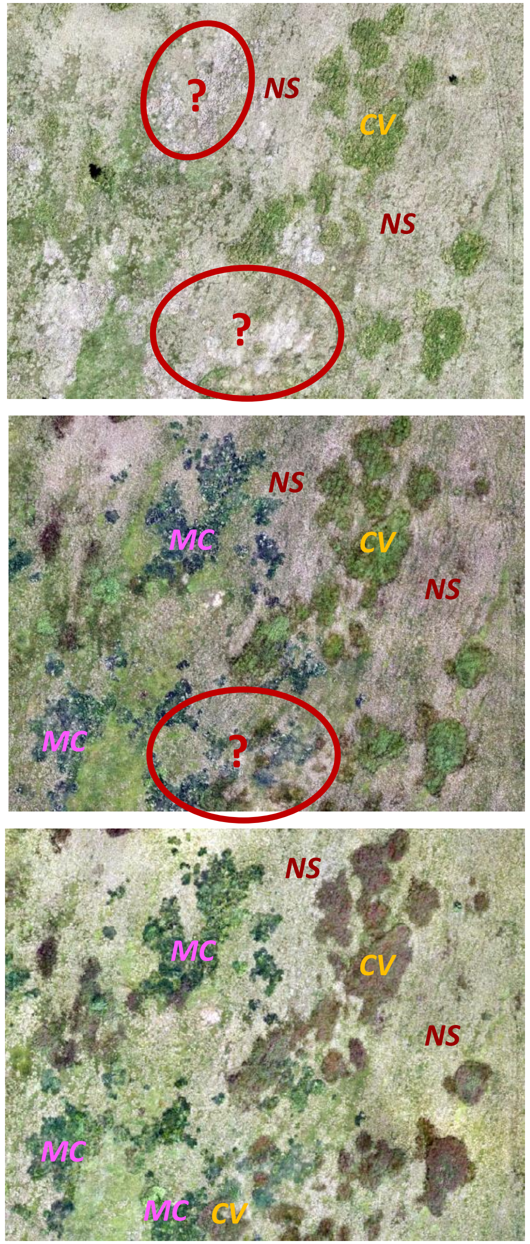
***Nardus stricta* (NS)** | ***Calamagrostis villosa* (CV)** | ***Molinia caerulea* (MC)**

June

July

August

Seasonal RGBMS images



June

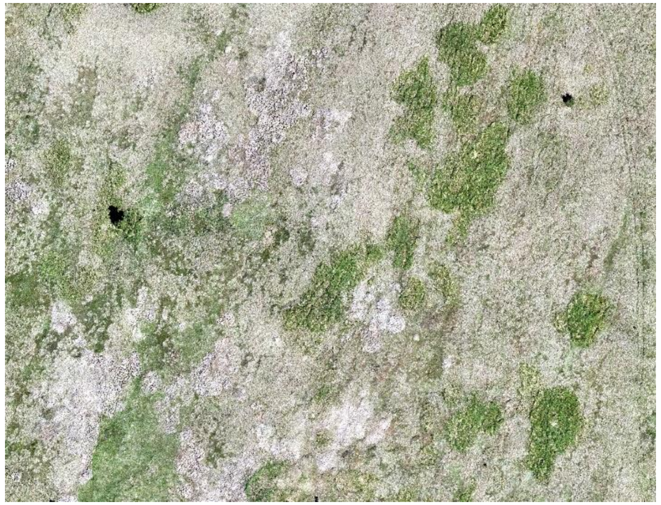
July

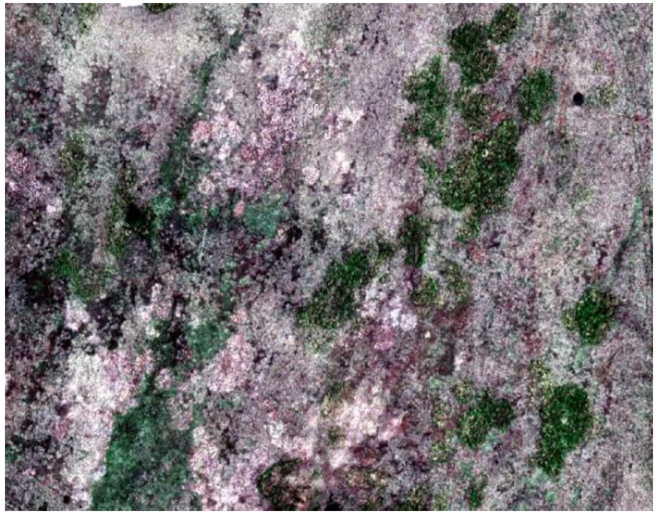
August

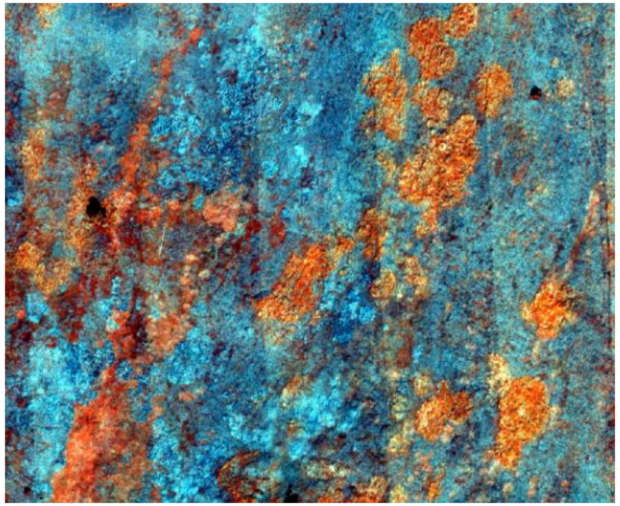
Results – Examples of the acquired data

True color RGB | True color HS | False color HS

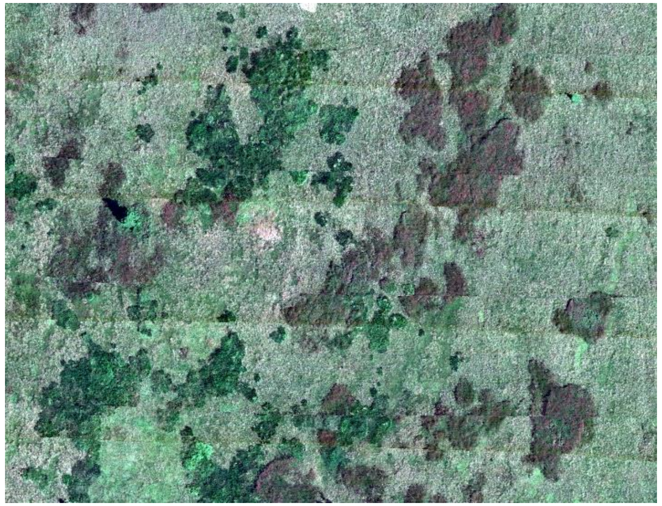
June



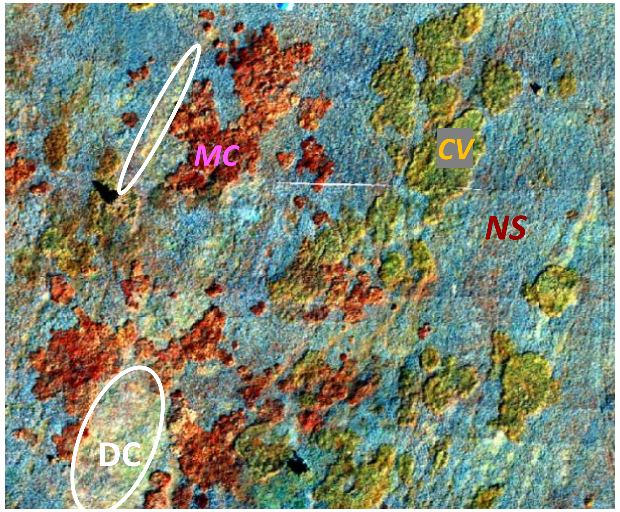




August

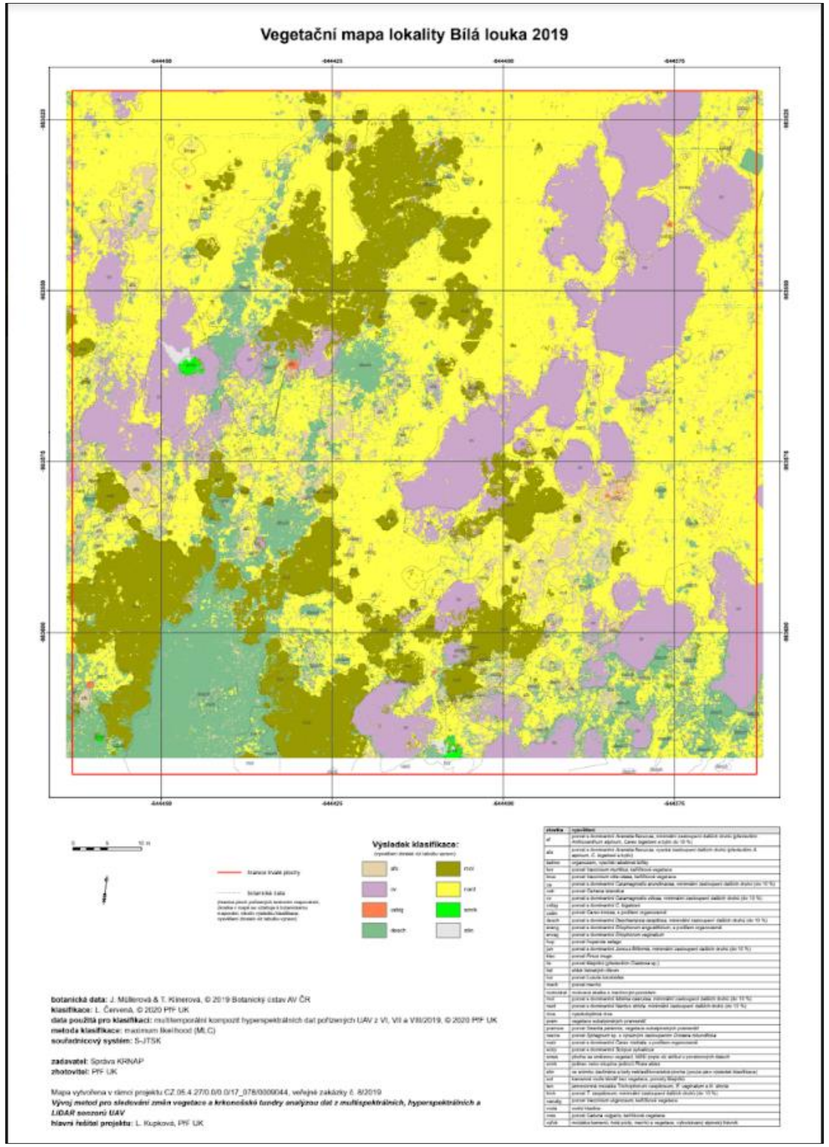


Deschmpsia cespitosa

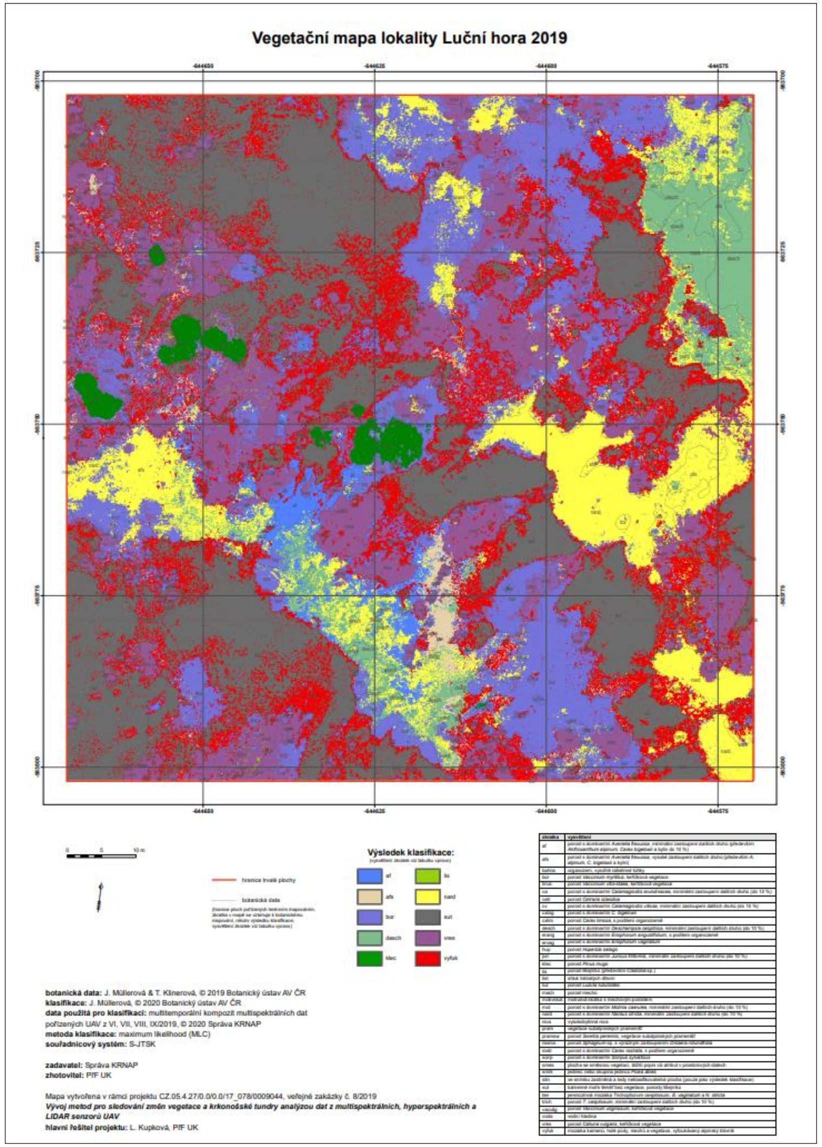


Results – Classification outputs

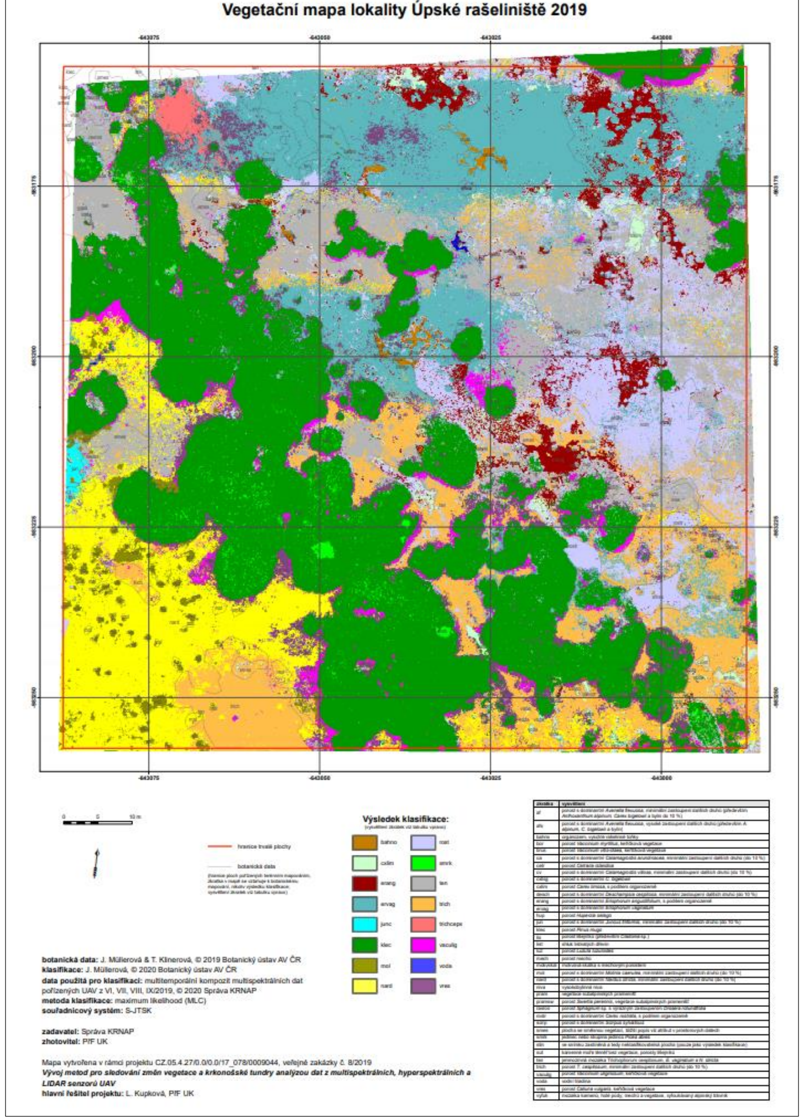
Bílá louka meadow



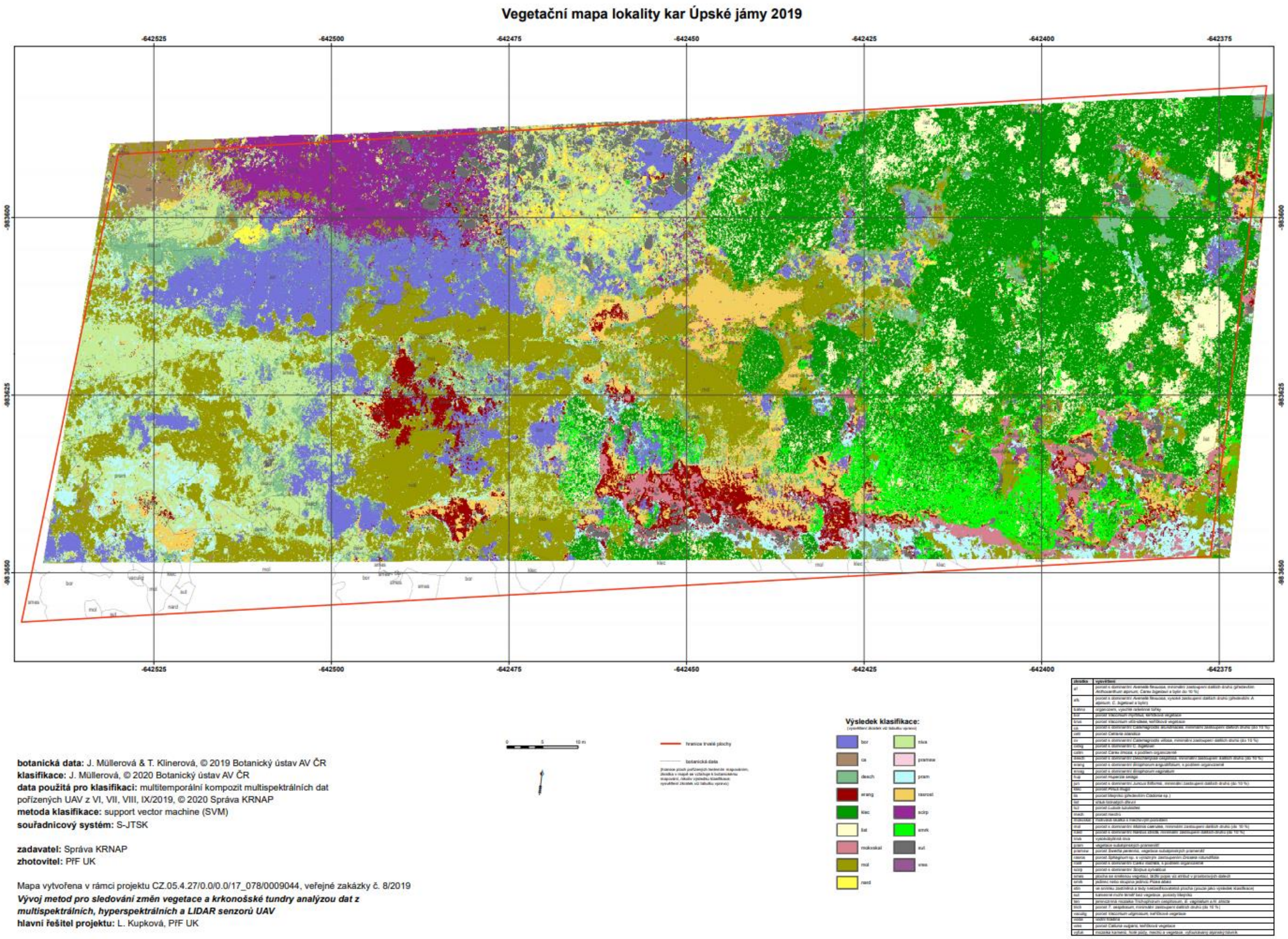
Luční hora Mt.



Úpské rašeliniště bog



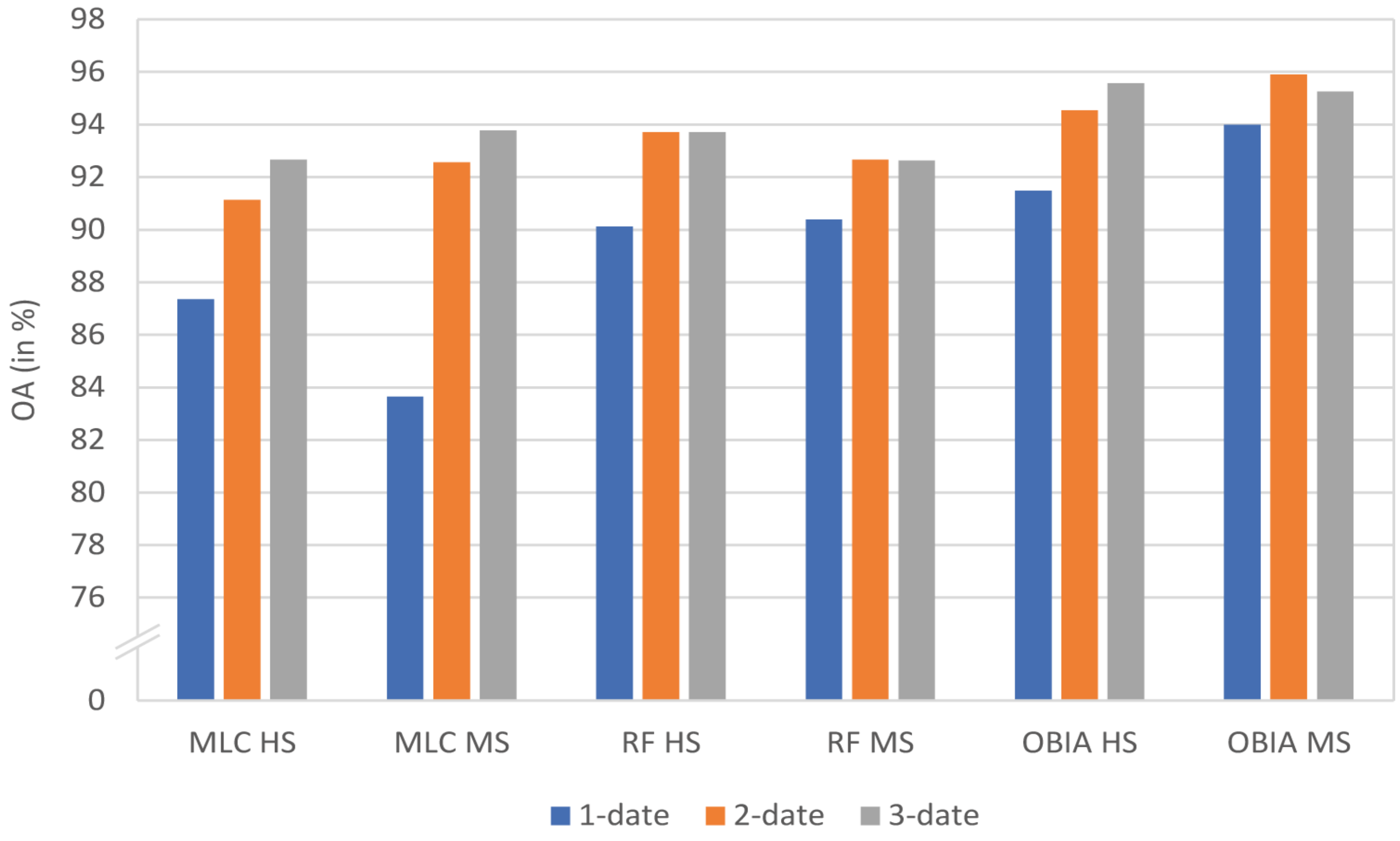
Results – Classification outputs: Kar Úpské jámy – corrie



Results – Overall accuracy – Bílá louka meadow

Temporal resolution	Parameters	UAV HS data			UAV MS data		
		MLC	RF	OBIA SVM	MLC	RF	OBIA SVM
Mono-temporal	**OA**	87.4	90.1	91.5	83.6	90.4	94.0
	month	July	July	August	July	July	July
	OBIA parameters			50, 90, 5			20, 60, 5
July, August	**OA**	91.1	93.7	94.6	92.6	92.7	**95.9**
	OBIA parameters			20, 60, 5			20, 60, 5
June, July, August	**OA**	92.7	93.7	**95.6**	93.8	92.6	95.3
	OBIA parameters			50, 90, 5			20, 60, 5

Comparison of OAs for UAV mono-temporal and multi-temporal data using MLC, RF, and OBIA SVM classifiers



Best F1-score achieved for individual species Bílá louka meadow

Species	Best F1-score (in %)			
	F1-score	**Data**	**Composite (month/s)**	**Classifier**
NS	**94.7**	MS	7,8	OBIA
CV	**99.4**	MS	6,7,8	OBIA
MC	**99.2**	MS	7,8	OBIA
DC	**96.3**	*HS*	6,7,8	OBIA
AF	59.0	MS	7,8	OBIA
CB	45.6	HS	6,7,8	OBIA

Species abbreviations: *NS - Nardus stricta, CV - Calamagrostis villosa, MC - Molinia caerulea, DC - Deschampsia cespitosa, AF - Avenella flexuosa, CB - Carex bigelowii*

Change detection – proposed methodology

The developed methodology takes into account the following key monitoring parameters:

- very high classification reliability (repeatability)
- high spatial resolution (capturing changes)
- easy feasibility (sustainability)
- affordability (sustainability)

Monitoring of changes – proposed methodology

- Priority species
- Level of small plots - 8 plots in eastern tundra and 8 in western
- New data for each plot once a 5 years
- UAV RGBMS data in combination with aerial images (dwarf pine, Picea abies), spatial resolution 9 cm
- 2 dates of UAV data acquisititon – July and August
- Botanical mapping in the first year (training and validation data)
- Ensemble methods – combination of MLC and RF (script in R)
- Accuracy over 80%

Priority species

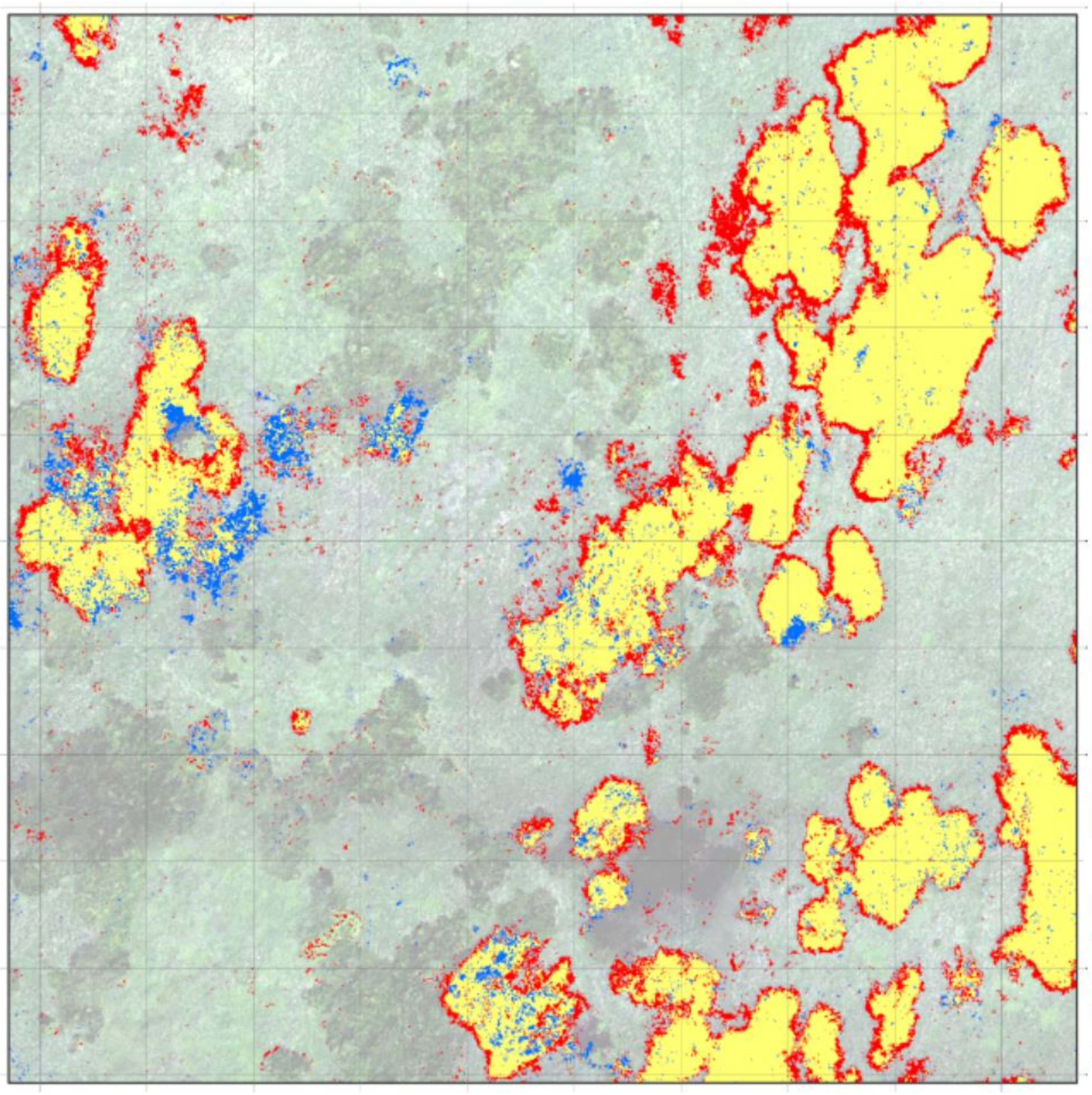
Calluna vulgaris stand, shrubby vegetation
Vaccinium myrtillus stand, shrubby vegetation
Pinus mugo stand
stand dominated by Eriophorum angustifolium with histosol
water
blockfields, mostly bare, with lichens
stand dominated by Calamagrostis villosa, minimal cover of other species (up to 10%)
stand dominated by Molinia caerulea, minimal cover of other species (up to 10%)
stand dominated by Nardus stricta, minimal cover of other species (up to 10%)
stand dominated by Deschampsia cespitosa, minimal cover of other species (up to 10%)
individual or a group of Picea abies

Change detection (methodology will be published)

- statistical (quantitative, non-spatial) - the result gives only overall information about the gain and loss for each class
- spatial – the result also gives information about where the change occurred

- Manual, Action plan, training

Final map output of change detection



Area: Bílá louka meadow

Class: *Calamagrostis villosa*

data1: MT_2019_07_10_2019_08_14_BL_MLC

data2: MT_2022_07_13_2022_08_11_BL_MLC

mapped Area m^2	user accuracy	producer accurvacy	Olofsson estimate m^2	95% confidence interval m^2
1844.89	98.72	97.67	1934.85	55.65
2250.76	94.97	90.08	2636.94	97.53

Change

increase		45 m²
stable		61 m²
decrease		28 m²

0 10 20 m

Conclusions

- We confirmed that UAV MS data with GSD of 9 cm are suitable for the reliable monitoring of dominant grass species in tundra with high accuracy and their changes

- The abundance/density/homogeneity of the species and its cover were essential for classification accuracy. The dedicated tests, by mainly using other classifiers, and other improvements should be continued in the future to increase the mapping accuracy of sparse growth and low-density species.

- We showed that adding a temporal dimension can be very beneficial, as the multi-temporal approach increased the accuracy in all cases. Our findings indicate that two dates might be sufficient for highly accurate classification results.

- Unexpectedly, the higher spectral resolution of HS data did not increase accuracies, and the results for the UAV MS and HS data were comparable. Spatial resolution was more important for the classification accuracy at the species level than the spectral resolution.

- These findings provide useful implications for nature conservation practices, because the price of suitable multispectral sensor/s and complexity of processing are significantly lower in comparison to hyperspectral data. Moreover, given weather constraints and costs, it is possible to reduce the number of dates to just two within the growing season without compromising the overall accuracy of the results.

- Unique method for change detection has been elaborated – UAV data, very detailed level, reliability

- **We look forward to seeing the results of the change monitoring in 4 years!**

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ORIGINAL PAPER

Towards resolving conservation issues through historical aerial imagery: vegetation cover changes in the Central European tundra

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ELSEVIER
Remote Sensing of Environment 294 (2023) 113645

Towards reliable monitoring of grass species in nature conservation: Evaluation of the potential of UAV and PlanetScope multi-temporal data in the Central European tundra

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ABSTRACT

Thank you for your attention!

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