2013

Evaluating UAS High-Resolution Aerial Photography (hrAP) to Support Everglades Wetland Plant Association Mapping Using Satellite Data

Daniel Gann
GIS-RS Center, Florida International University, gannd@fiu.edu

Jennifer H. Richards
Department of Biological Sciences, Florida International University, richards@fiu.edu

Evaluating UAS High-Resolution Aerial Photography (hrAP) to Support Everglades Wetland Plant Association Mapping Using Satellite Data

Daniel Gann and Jennifer Richards

Wetland Vegetation Monitoring

Three challenges for monitoring vegetation in greater Everglades:

- spatial heterogeneity (complexity) of vegetation (landscape pattern)
- natural intra-annual, inter-annual and decadal temporal dynamics
- the large spatial extent

Remote sensing

- can generate information over large spatial extents without disturbing the environment and
- can provide greater temporal resolution than traditional sampling and mapping techniques

BUT to use RS to monitor vegetation change

- need rapid and affordable methods to gather ground reference information in order to train algorithms and assess the accuracy of remote sensing products

Vegetation Classification

Problem 1: disjunction of class scale defined vs. detected or analyzed

→ misleading conclusions about extant vegetation patterns

Problem 2: scale dependence of plant community definitions

→ e.g., species sampled 1 m^2 differs from 50 m^2

→ vegetation surveys and map accuracy assessment - costly field sampling procedures or using helicopter surveys (rapid assessments)

→ assessment is performed for a specific scale and for a single map only

- study of plant association patterns and their dynamics across spatial scales for large spatial extents requires spatially explicit vegetation information
- difficult to gather this type of information via field survey sampling techniques, which generally sample at a single scale

Problem 3: sampling error and confidence

→ vegetation classifications derived from single sample

→ establishment of classification schemes that are valid for multiple scales of detection and analysis

→ using high-resolution images captured by unmanned aerial systems (UAS) may offer a more affordable, reliable and repeatable assessment that can occur at various scales and that can provide historic reference data for multiple mapping efforts.

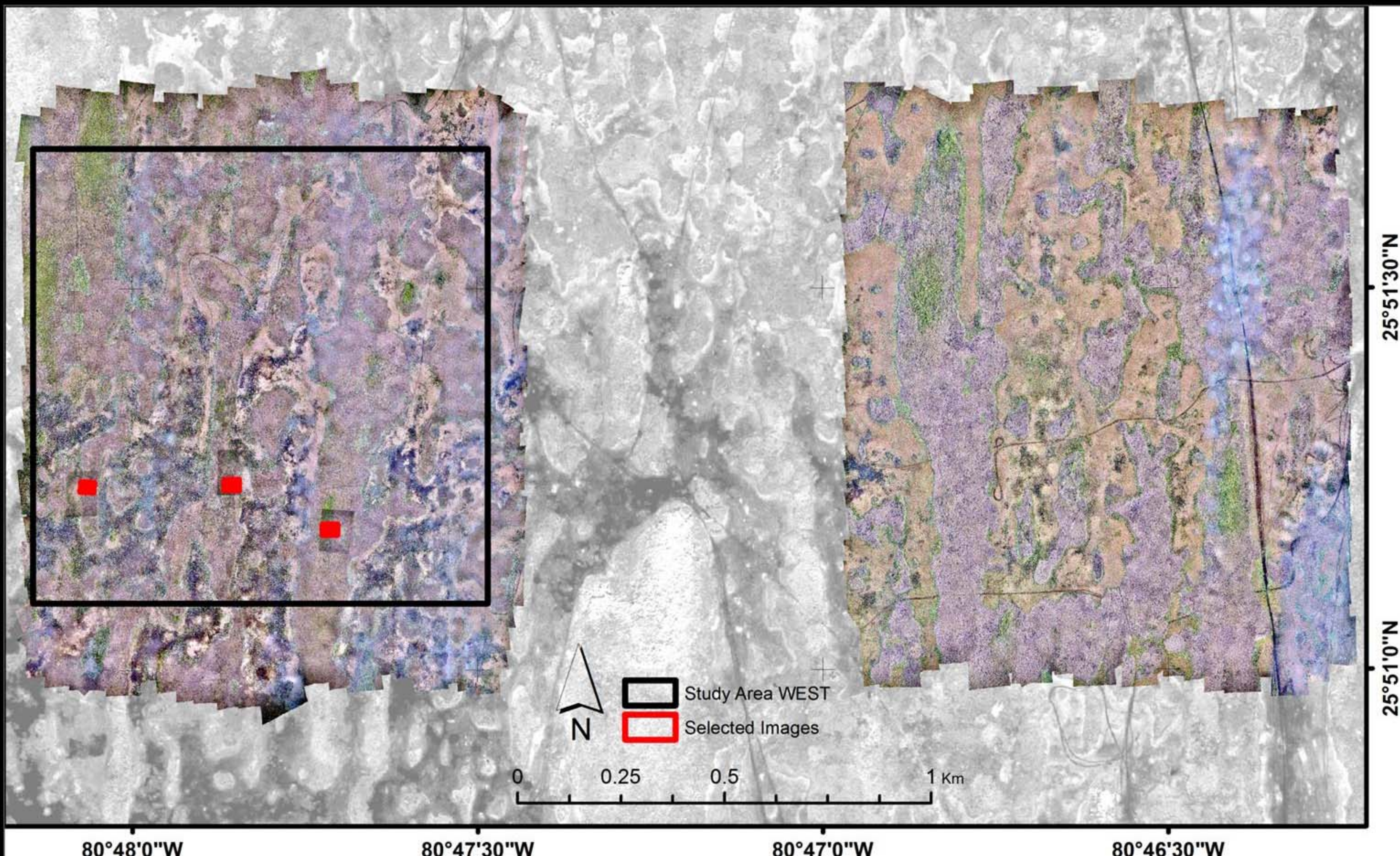
Solution: Scale specific vegetation classes with clearly defined metrics of relative abundance boundaries

High Resolution UAS Aerial Photography

- determine spatial accuracy of geo-referenced AP
  - co-registration of hrAP to field site surveys and geo-referenced satellite data is crucial
  - requirement: AP and satellite data co-registered within 0.5 times the detection resolution (satellite) -> confidence of training sample selection for supervised classifications and support during accuracy assessment

- determine if image resolution is appropriate to detect vegetation classes
  - evaluate detectability of vegetation at species level and of vegetation associations once formulated
  - characteristics of the hrAP that are important in this process are resolution and quality consistency across the study area

High Resolution UAS Aerial Photography Mosaics

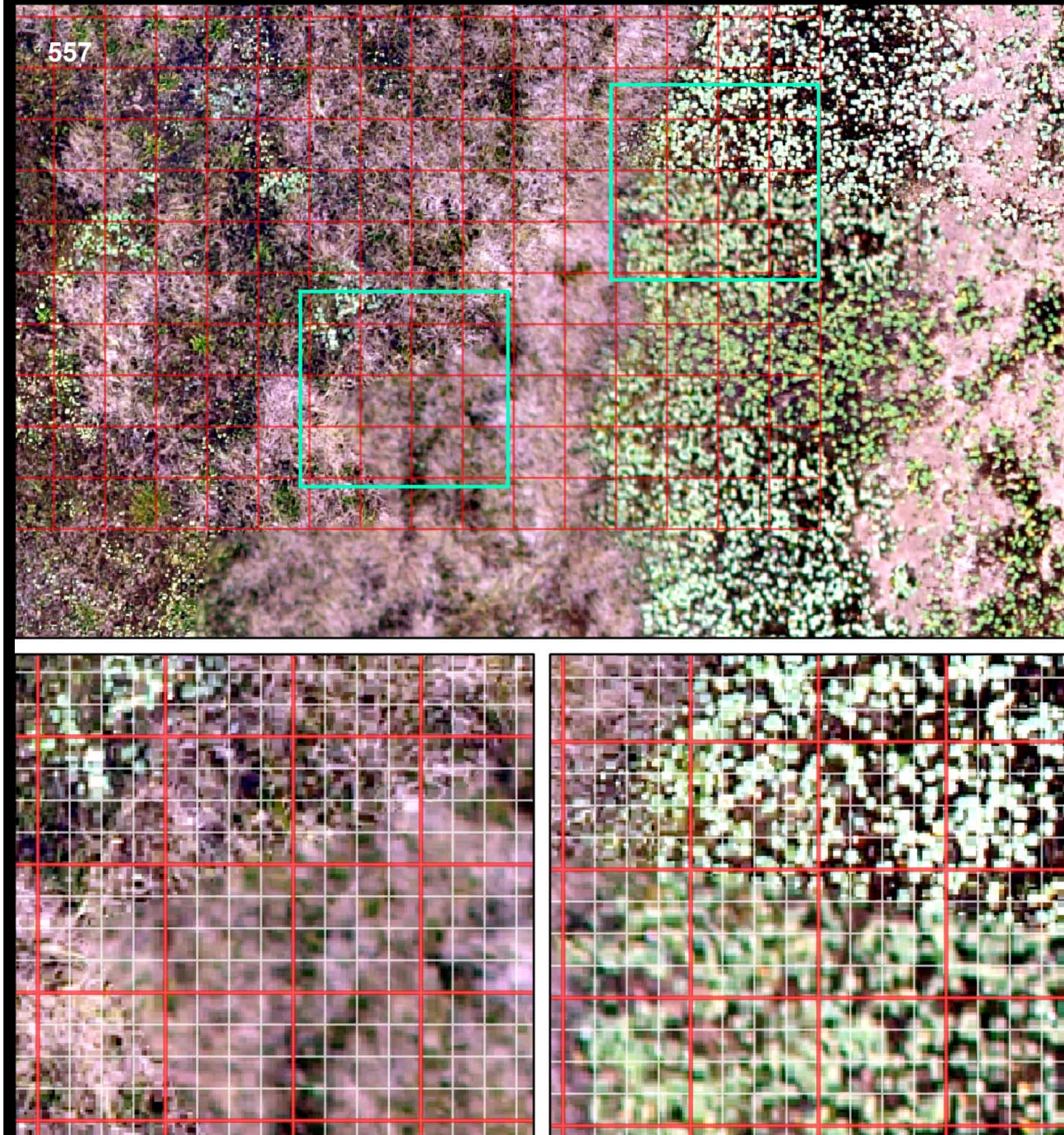


Objective 1

AP evaluation

- spatial accuracy to support vegetation identification and detection for a specific target resolution of 2 m (spatial resolution of WV-2 satellite data)

- image resolution to detect presence and estimation of relative abundance of Everglades wetland species from AP mosaic



Methods

spatial accuracy
Reference: 1-ft resolution ortho-rectified aerial photograph of 2011 (CERP).
Sample size: 16 reference locations spread across the full scene

Results

→ positional accuracy not uniform across the mosaic

→ shift in x and y dimensions was between 5 and 7 meters in either dimension

→ directional RMSE
2.8 m (-4.3 to +0.9 m) lon.
4.5 m (-0.5 to -7.1 m) lat

Euclidean RMSE 5.2 ± 2 m

Image quality and ground resolution not homogeneous across mosaic

Objective 1

AP evaluation

- spatial accuracy to support vegetation identification and detection for a specific target resolution of 2 m (spatial resolution of WV-2 satellite data)

- image resolution of raw imagery at 1cm and 3 cm to detect presence and estimation of relative abundance of Everglades wetland species.

	Low Altitude	High Altitude
East number of Images	97	931
West number of Images	91	1063
Mean Altitude (mag)	35.7	136.1
Standard Deviation (mag)	8.4	11.8

Camera Type	Dimension	Value	Units	Image Name	Flight Altitude (mag)	Nominal Ground Resolution (cm)	2nd Order Polynomial RMSE (cm)	Number of Reference Points	Spatial Reference Resolution (cm)
Olympus E420	sensorWidth	17.3	mm	20120816222532_513	33.7	0.64	16.7	10	1.06
	sensorHeight	13	mm	20120815030421_285	128.6	2.44	15.1	46	3.15
	resWidth	3648	dpi	20120816222532_557	34.2	0.65	12.8	58	1.09
	resHeight	2736	dpi	20120814230041_255	128.2	2.43	26	78	3.07
	cropFactor	2.02	-	20120816222532_550	32.2	0.61	28.5	54	1.03
	focalLength	25	mm	20120814230041_719	133.5	2.53	28.5	184	3.1

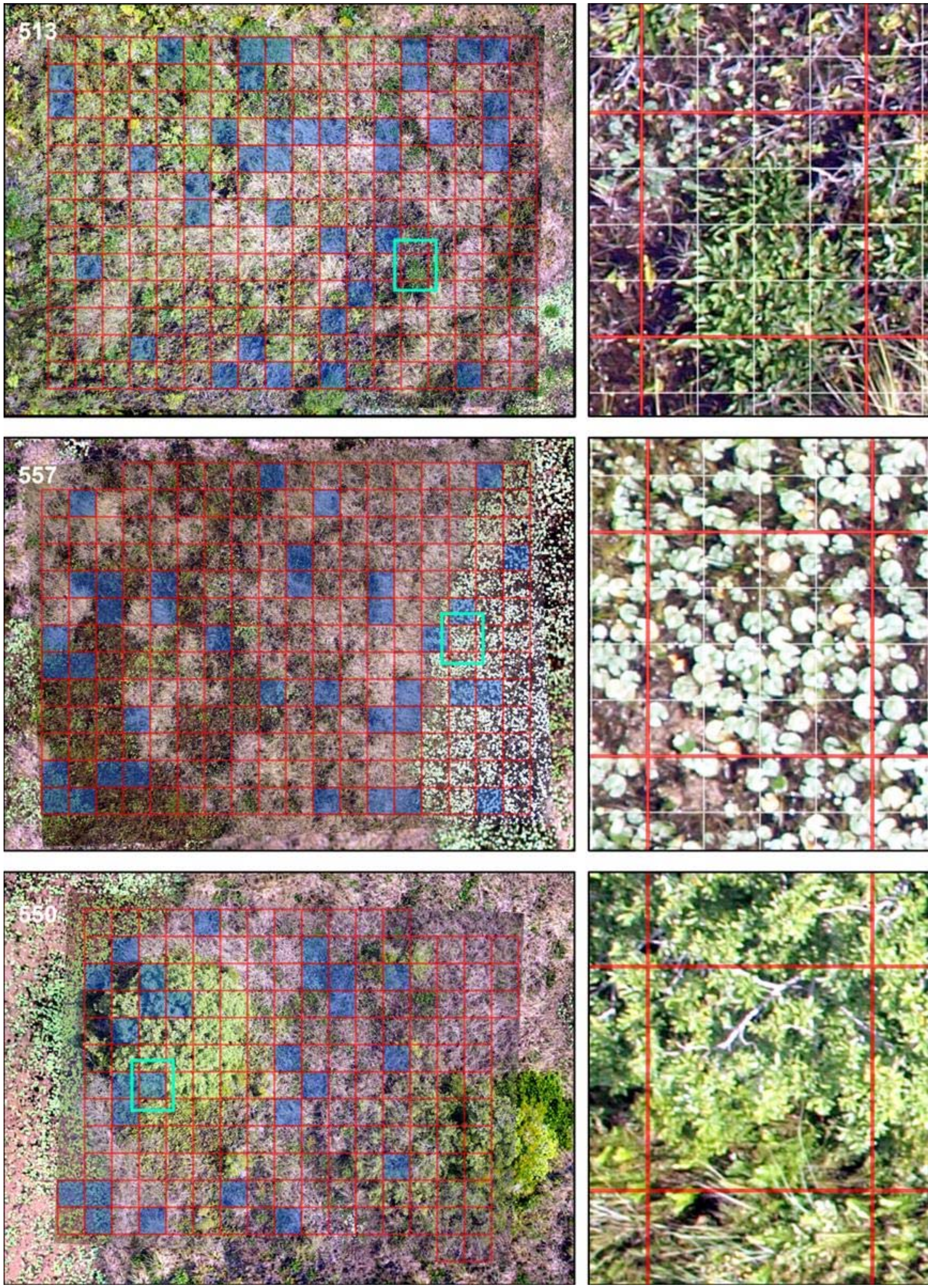
3 images - variability in species presence

- medium res. (grey) referenced to 1ft AP and field data
- high res. (white) referenced to medium res. images

- altitudes 33.7, 34.2 and 32.2 mag
- geo-referenced (ArcGIS) 2nd order polynomial
- RMSE 16.7, 12.8, and 28.5 cm
- nominal spatial resolution of approximately 1 cm for all referenced images

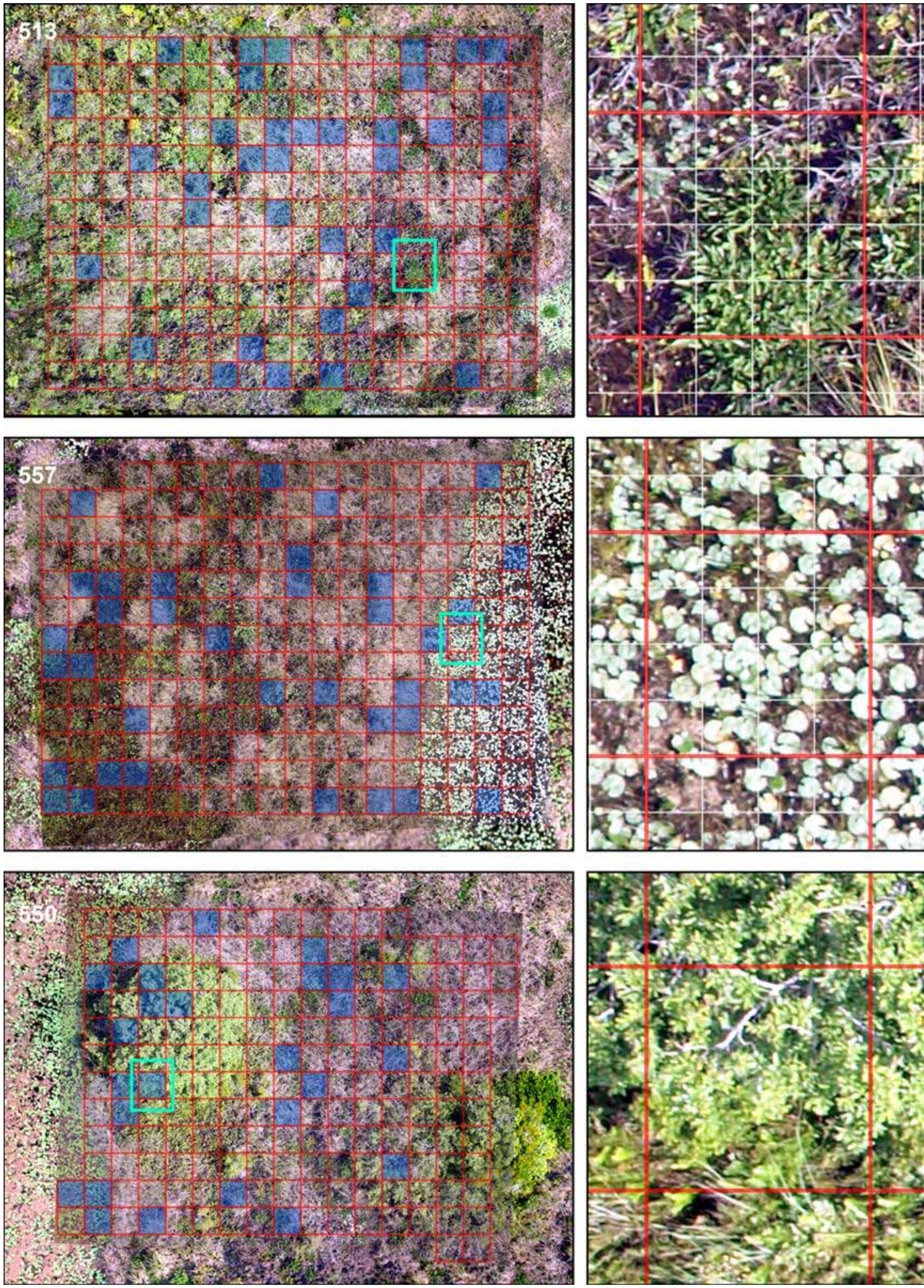
Vegetation classes considered in the visual interpretation process. *BOLD CAPITALS* indicate morphological groups. *CAPTIALS* **indicate sub-group.**

Vegetation Classes			
FLOATING BROADLEAF	***EMERGENT BROADLEAF***	***SHORT GRAMINOID***	***SHRUB***
Nymphaea odorata	*FERN*	*Panicum hemitomon*	*Salix caroliniana*
Nymphoides aquatica	*Acrostichum danaeifolium*	*Rhynchospora tracyi*	*Myrica cerifera*
Nuphar advena	*Peltandra virginica*	*Rhynchospora inundata*	*Chrysobalanus icaco*
FLOATING NON-BROADLEAF	*Crinum americanum*	*Eleocharis ssp.*	*Cephalanthus occidentalis*
Utricularia foliosa	*Sagittaria lancifolia*	***TALL GRAMINOID***	***TREE***
Utricularia purpurea	*Pontederia cordata*	*Cladium jamaicense*	*Annona glabra*
PERIPHYTON	*Thalia geniculata*	*Typha domingensis*	*Magnolia virginiana*
	HERBACEOUS		*Ilex cassine*
			Persea ssp.
			Ficus ssp.



Methods

- relative abundance estimates each 2x2 m grid cell divided into 16 0.25 m2 sub-grid cells
- both interpreters independently assigned relative abundance estimates for each 2x2 m grid cell based on coverage of the 16 cell sub-grid estimation
- subset of 100 grid cells was sampled with a simple random sample without replacement
- blue transparent grid cells also interpreted from 3 cm resolution images



1 cm resolution geo-referenced aerial photographs. The right panels show 1:50 zoom areas; these locations are outlined in turquois in the overview maps to the left. Red squares are 2 x 2 m grid cells;

Top right: Cell with about 44% *Peltandra virginica*; 12.5% *Nymphaea odorata*, periphyton and *Cephalanthus occidentalis*; and 6% *Nymphoides aquatica* and herbaceous vegetation.

Center right: 75% *Nymphaea odorata*; 18.25% periphyton and short graminoids.

Bottom right: 75% *Magnolia virginica*; 12% ferns; and 6% periphyton and *Myrica cerifera*.

Results for 2 interpreters

Species profile for presence/absence

Vegetation Class	% Agree	% Int 1	% Int 2	% Both	% Either	% Det
Nymphaea odorata	97.7	1.7	0.6	16.8	2.3	19.1
Nymphoides aquatica	96.8	2.6	0.6	8.5	3.2	11.7
Utricularia foliosa	94.6	4.0	1.4	4.3	5.4	9.7
Utricularia purpurea	94.8	4.8	0.5	4.2	5.2	9.4
FERN	89.5	3.5	6.9	44.7	10.5	55.2
Peltandra virginica	89.2	7.7	3.1	23.1	10.8	33.9
Crinum americanum	97.2	1.5	1.2	7.7	2.8	10.5
Sagittaria lancifolia	97.8	1.5	0.6	2.0	2.2	4.2
Pontederia cordata	99.1	0.9	0.0	0.0	0.9	0.9
Panicum hemitomon	100.0	0.0	0.0	0.3	0.0	0.3
Cladium jamaicense	97.8	0.8	1.4	71.5	2.2	73.7
Salix caroliniana	95.4	3.7	0.9	15.9	4.6	20.5
Myrica cerifera	98.2	0.5	1.4	4.3	1.9	6.2
Chrysobalanus icaco	99.7	0.0	0.3	0.9	0.3	1.2
Cephalanthus occidentalis	94.1	3.2	2.6	11.6	5.9	17.4
Annona glabra	99.2	0.5	0.3	5.9	0.8	6.6
Magnolia virginiana	99.1	0.5	0.5	6.6	0.9	7.6
Persea ssp.	99.4	0.3	0.3	0.3	0.6	0.9
PERIPHYTON	94.5	1.9	3.7	26.5	5.6	32.1

Morphological group profile for presence/absence

Vegetation Class	% Agree	% Int 1	% Int 2	% Both	% Either	% Det
FLOATING BROADLEAF	97.4	1.9	0.8	21.4	2.6	24.0
FLOATING NON-BROADLEAF	92.5	6.3	1.2	7.2	7.6	14.8
EMERGENT BROADLEAF	92.3	1.9	5.9	71.8	7.7	79.5
SHORT GRAMINOID	97.1	2.0	0.9	5.2	2.9	8.2
TALL GRAMINOID	97.8	0.8	1.4	71.5	2.2	73.7
HERBACEOUS	78.1	6.2	15.7	11.1	21.9	33.0
SHRUB	91.8	4.9	3.2	30.7	8.2	38.8
TREE	97.8	0.9	1.2	12.8	2.2	15.0
PERIPHYTON	94.5	1.9	3.7	26.5	5.6	32.1

Results

Vegetation Class	% Int 1	% Int 2	% Mean	% Diff	% relDiff
FLOATING BROADLEAF	0.0	0.0	0.0	0.0	-
Nymphaea odorata	6.2	6.3	6.3	0.1	1.6
Nymphoides aquatica	0.9	0.8	0.9	0.1	11.1
Utricularia foliosa	0.6	0.4	0.5	0.2	33.3
Utricularia purpurea	1.0	0.4	0.7	0.6	60.0
EMERGENT BROADLEAF	1.0	2.2	1.6	1.2	54.5
FERN	12.0	12.2	12.1	0.2	1.6
Peltandra virginica	4.1	3.8	4.0	0.3	7.3
Crinum americanum	1.1	1.1	1.1	0.0	0.0
Sagittaria lancifolia	0.4	0.4	0.4	0.0	0.0
Pontederia cordata	0.1	0.0	0.1	0.1	100.0
SHORT GRAMINOID	0.8	1.0	0.9	0.2	20.0
Panicum hemitomon *	0.0	0.0	0.0	0.0	0.0
TALL GRAMINOID	0.0	0.1	0.1	0.1	100.0
Cladium jamaicense	42.3	40.9	41.6	1.4	3.3
HERBACEOUS	2.1	2.4	2.3	0.3	12.5
SHRUB	0.6	0.7	0.7	0.1	14.3
Salix caroliniana	6.8	5.7	6.3	1.1	16.2
Myrica cerifera	1.0	1.1	1.1	0.1	9.1
Chrysobalanus icaco	0.2	0.3	0.3	0.1	33.3
Cephalanthus occidentalis	3.5	3.1	3.3	0.4	11.4
TREE	0.1	0.1	0.1	0.0	0.0
Annona glabra	2.6	2.3	2.5	0.3	11.5
Magnolia virginiana	4.3	4.3	4.3	0.0	0.0
Persea ssp.	0.1	0.2	0.2	0.1	50.0
PERIPHYTON	5.9	5.3	5.6	0.6	10.2

Species profile percent difference

%Diff = absolute percent difference between interpreter 1 (Int 1) and interpreter (Int 2)

%relDiff = relative difference - the difference normalized by the maximum relative abundance estimated by either interpreter 1 or 2

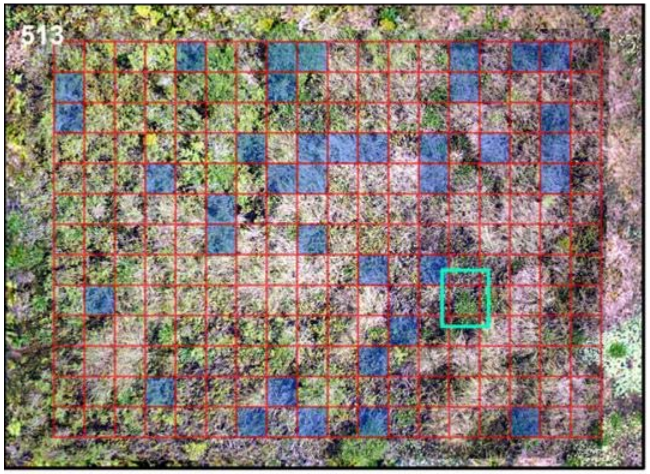
* species detected by both interpreters at percentages less than 0.1% but in full agreement (0% difference).

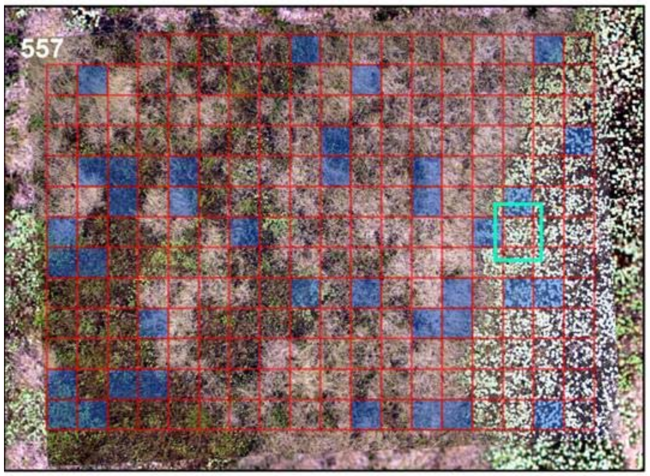
Results

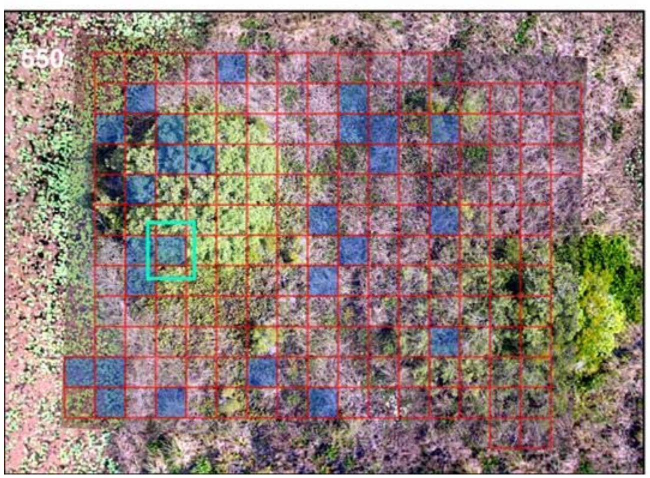
Site profile summary

- presence/absence
- relative abundance differences
- diversity differences

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
relAbn SpecDif	0.0	6.3	12.5	12.6	18.8	68.8
relAbn SpecDifCor	0.0	6.3	9.4	11.3	15.6	62.5
relAbn MorphDif	0.0	3.1	9.4	10.1	15.6	68.8
Pres/Abs SpecAgree	80.8	92.3	96.2	95.6	100.0	100.0
Pres/Abs. MorphAgree	55.6	88.9	100.0	93.3	100.0	100.0
Diversity Int1	1.0	2.0	3.0	3.3	4.0	9.0
Diversity Int2	1.0	2.0	3.0	3.4	4.0	10.0
Diversity Dif	0.0	0.0	0.0	0.3	0.0	4.0







High- vs. Medium Resolution Photography

- 100 random grid cells

species overlap 87.5% (14 of 16)

- minor presence discrepancy
  - 1/16 of cell tree vs. 1/16 floating broadleaf

Relative abundance summarized at morph. groups:

- highest difference for Periphyton -3.1% vs. +4.2%
- difference at high res. 1.1% - medim res. 8.4%

- emergent broadleaf and tall graminoids increased in abundance

- reduction in detection precision (increase in morph. vs. species recognition) varied by morph. groups
  - emergent broadleaf +19.9% and 36.6%
  - shrub +7.1% and +35.41%
  - ferns -3.7% and -4.1%
  - species with consistent increase *Nymphoides aquatica* and *Cladium jamaicense*

Conclusion

Recognizing plant species in the hrAP was possible at the 1 cm resolution but limited at resolution of 3 cm for majority of species included in species list

High agreement of visual interpretation

→ process is reproducible

→ can provide exhaustive presence and abundance data for vegetation

- → at relatively fine taxon scale
- → across large extents
- → as a permanent record

Ability to interpret vegetation in photographs requires training and experience

→ even for experienced photo-interpreters and field botanists

→ additional experience comparing image and species on ground would have increased ability to detect and discriminate

Conclusion

Species detection depends on timing of acquisition
→ considering species-specific phenological stages of vegetation allows for species-specific campaigns (least likely confused with other vegetation)

radial distortion due to the nature of aerial photography needed to be considered when interpreting regions in the center or on the edges of the photographs
→ additional understanding of how species' appearance varies between centers vs. edge of AP (i.e., varying degrees of planar vs. profile views)

→ tall emergent linear vegetation - short graminoid species
→ tree and shrub species, seen from a point-of-view that is very different how they are viewed on the ground

Recommendations

- We do not recommend to attempt to detect and identify vegetation at the species or morphological group level from the mosaic

- Spatial accuracy of geo-referencing: reflective field targets for easier registration process

- Detection: Acquisition of higher resolution images
  - How to increase shutter speed to capture continuous images with overlap at low flight altitudes?
  - NIR

- Sample representativeness: Acquire AP for smaller areas across larger spatial extents to capture full regional vegetation heterogeneity

Objective 2 Introduction

Mapping of vegetation patterns over large extents using remote sensing methods requires field sample collections for two different purposes:

(1) the establishment of plant association classification systems from samples of relative abundance estimates

(2) training for supervised image classification and accuracy assessment of satellite data derived maps

Challenges: - establishment of confidence in results
- analysis across multiple spatial scales

hrAP

- alternative to extensive, invasive, field sampling
- can provide large volume, spatially continuous, reference information
- can meet challenges of confidence building and multi-scale analysis

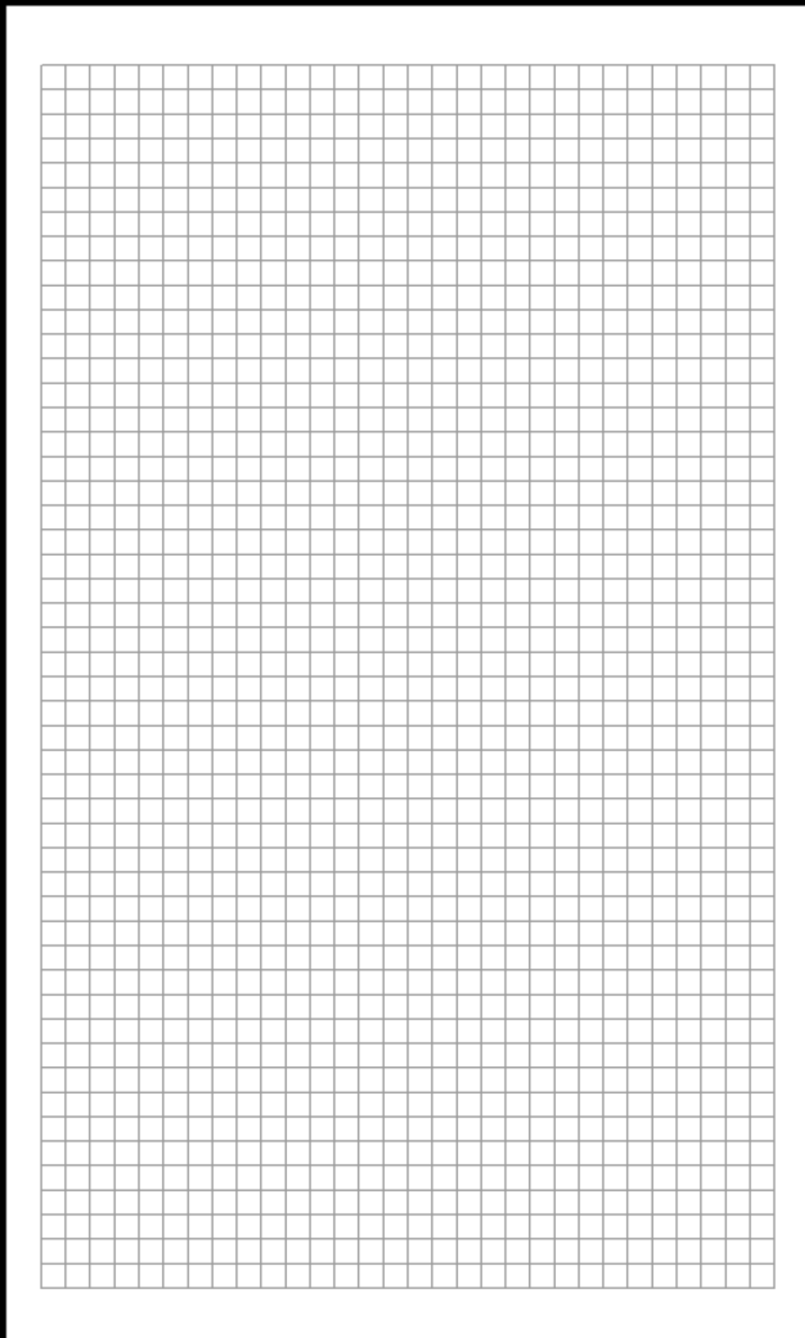
Objective 2

Evaluation of stability and consistency of plant association definitions at multiple sampling intensities derived from continuous hrAP interpreted vegetation data

Methods

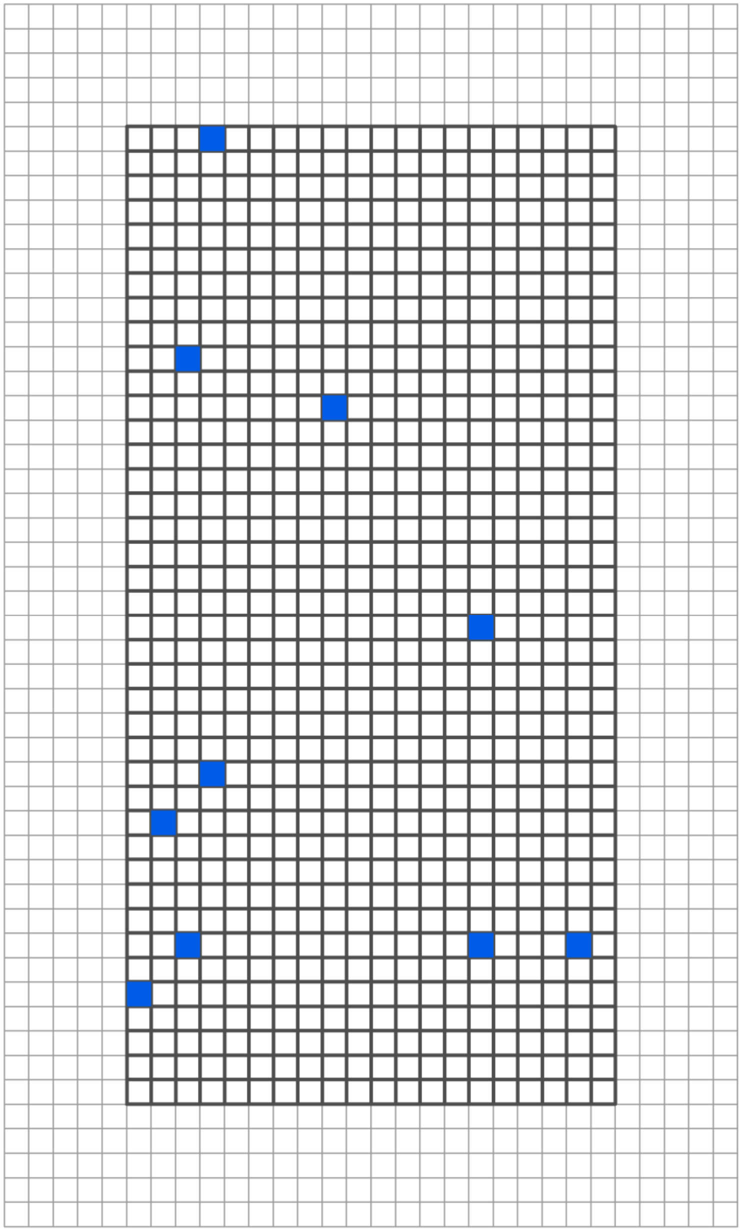
Classification of plant associations based on non-hierarchical clustering (i.e., k-means) of relative abundance estimates of plant species

→ Sample from relative abundance estimates at grid size of 2 m
→ Derive association definitions
→ Use iterative re-sampling with subsequent cluster analysis to provide multiple plant association definitions
→ Combine re-sampling results for confidence building



Re-sampling base map

- spatially explicit map of visually interpreted relative plant abundance survey information at 2x2m (4 m^2) grid cell

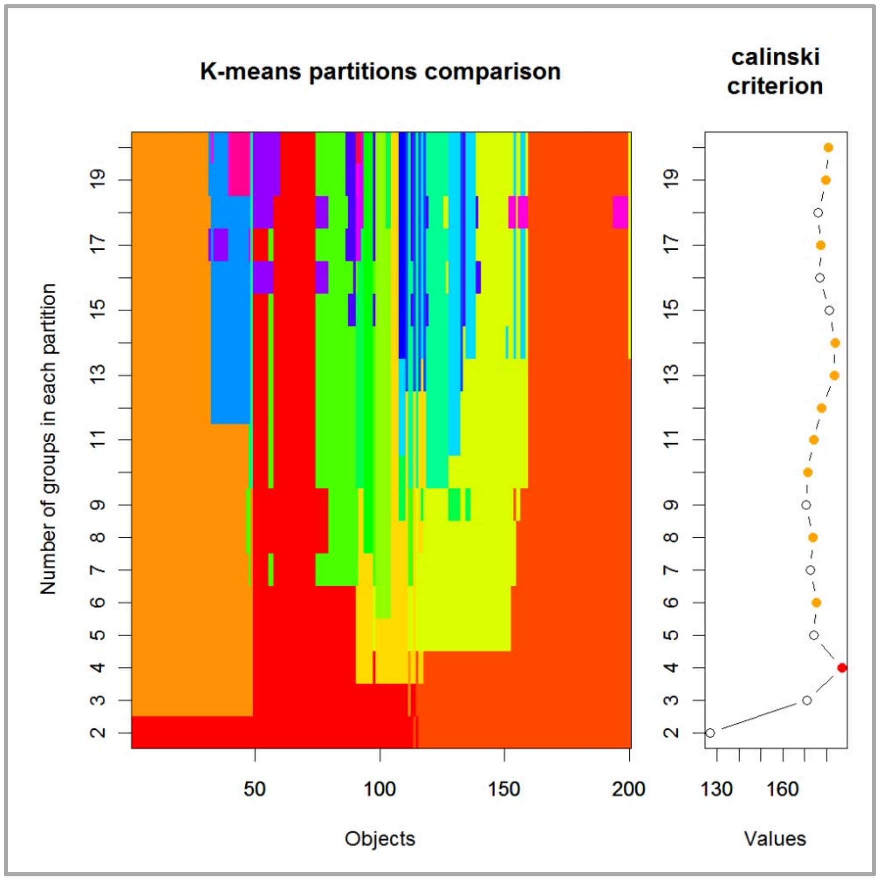


Re-sampling base map

- sample frame cells (black)
- buffer zone cells (light grey) to avoid edge effects
- randomly sampled grid cells (blue)

Cluster Analysis

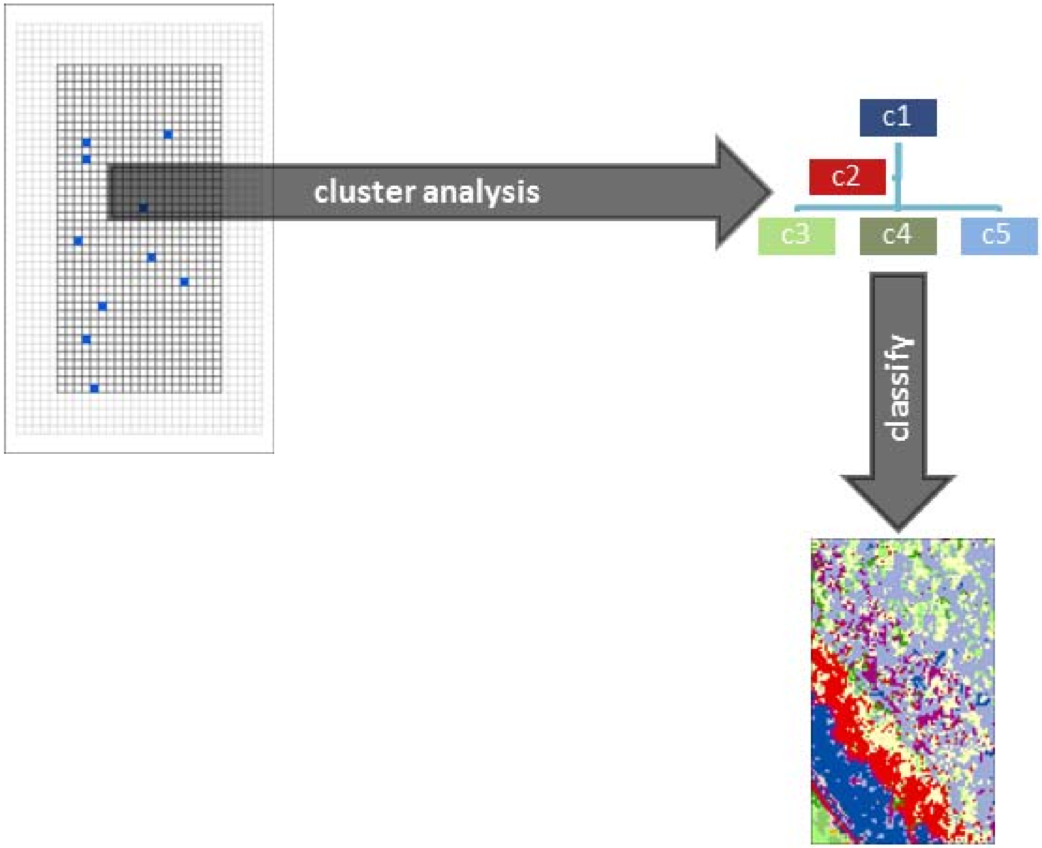
- species associations determined from cluster analysis of relative abundances of random sample



Cluster Analysis

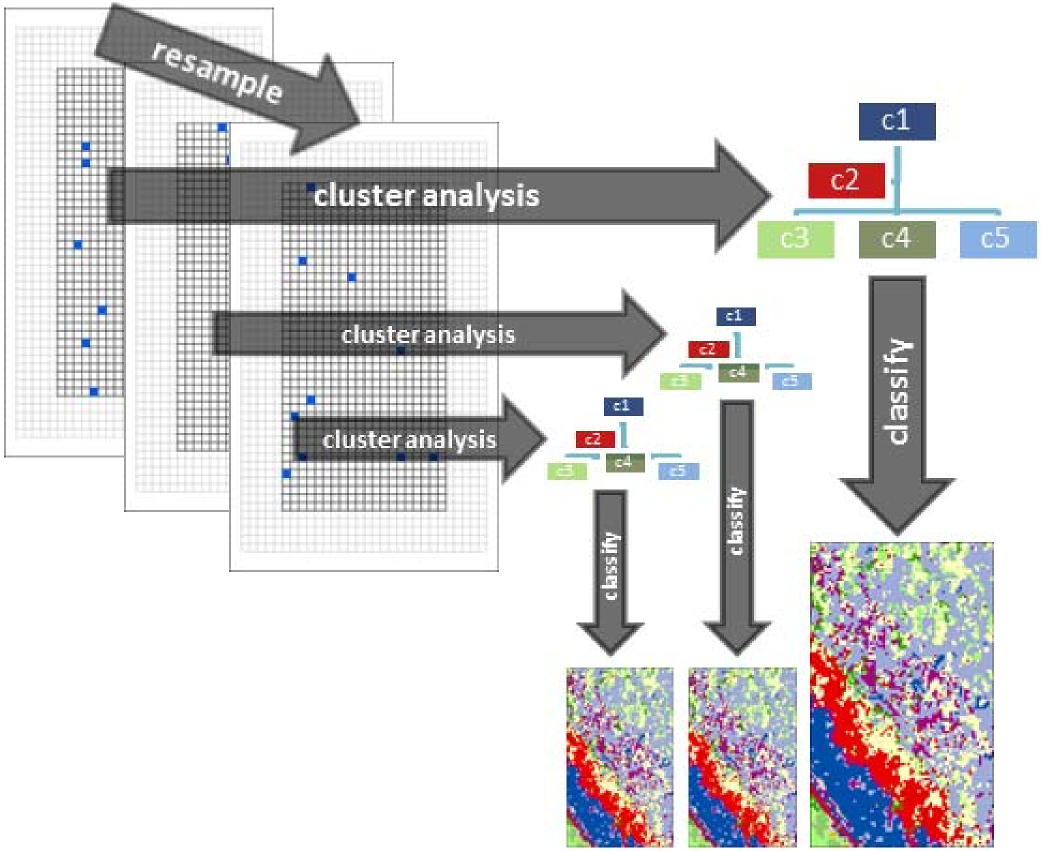
- statistics of interest
  - smallest number of classes that contain the largest number of significantly positively associated species
  - cluster associated species-specific relative abundance distributions of all samples
  - criterion used to determine the smallest number of classes and associations Calinski-Harabasz (Caliński and Harabasz 1974)

- constraints
  - at least 3 sites per cluster



Classification

- all grid cells classified based on cluster result
- classifier: random forest (Breiman 2001, 2002)

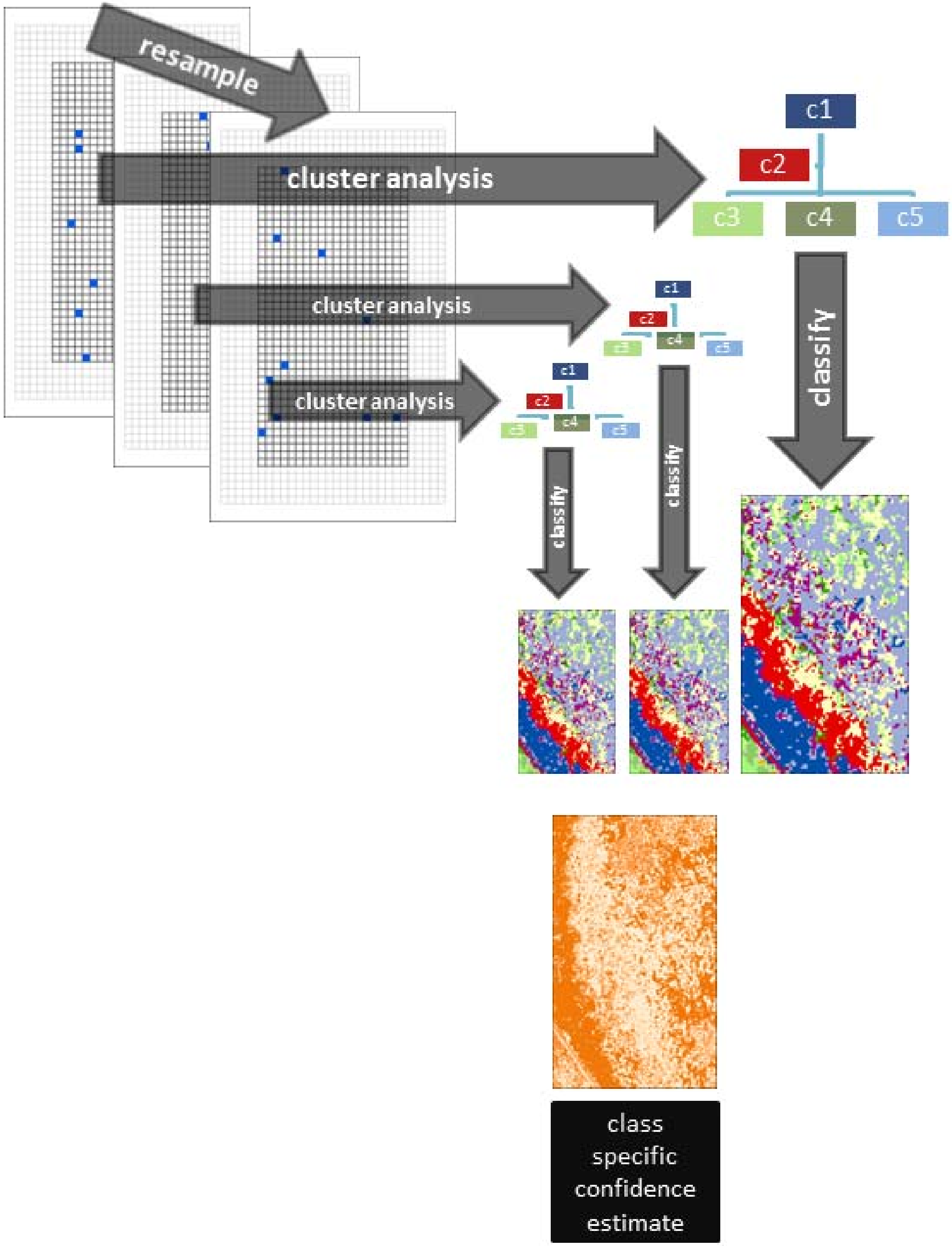


Re-sampling framework

- allows for evaluation of stability of class descriptors

stability criteria

(1) distribution of optimal number of clusters for all sampling intensities of interest



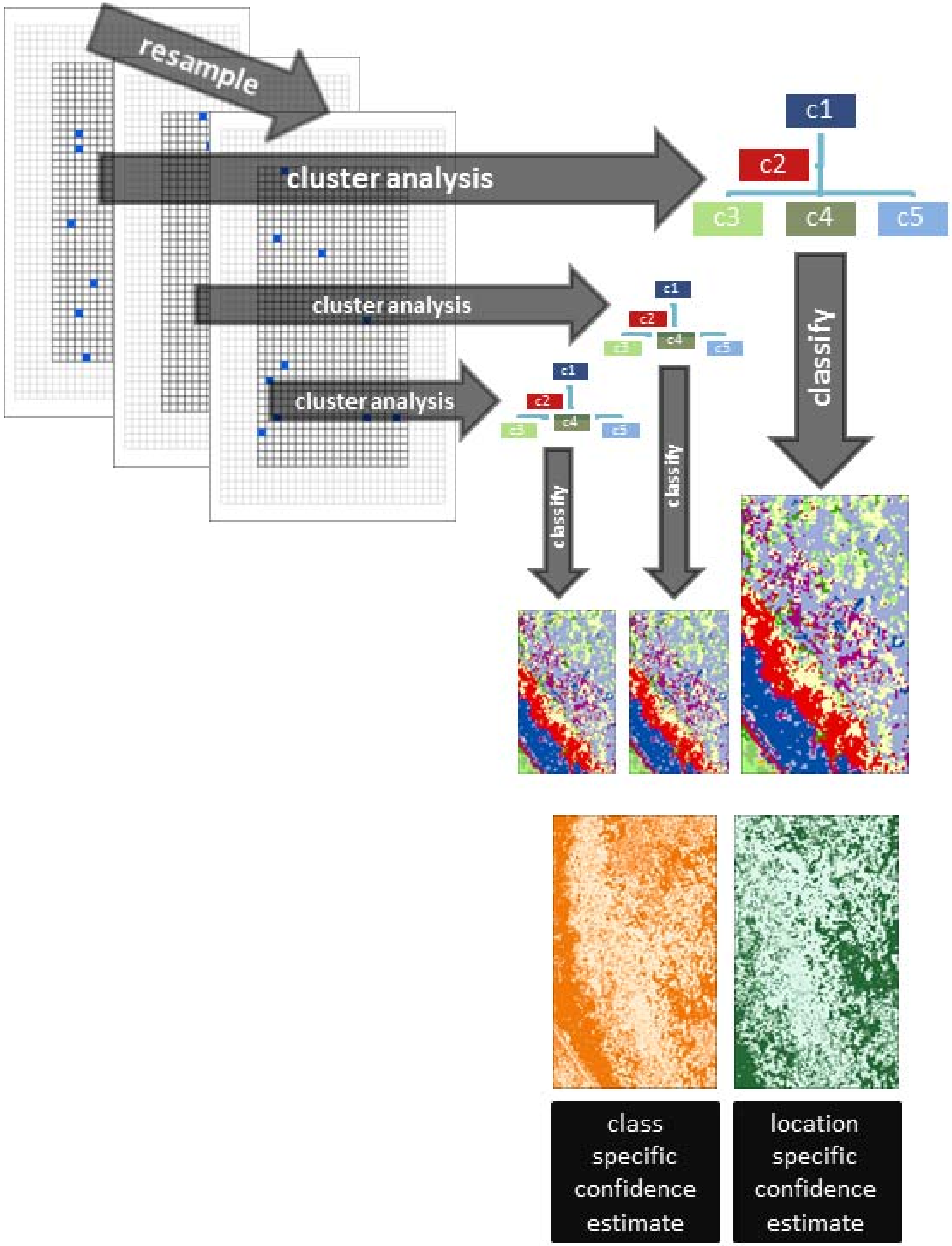
Re-sampling framework

- allows for evaluation of stability of class descriptors

stability criteria

(1) distribution of optimal number of clusters for all sampling intensities of interest

(2) class-specific model-based error estimates and class-specific classification probabilities of sites that had not been included in the clustering and classifier establishment routine



Re-sampling framework

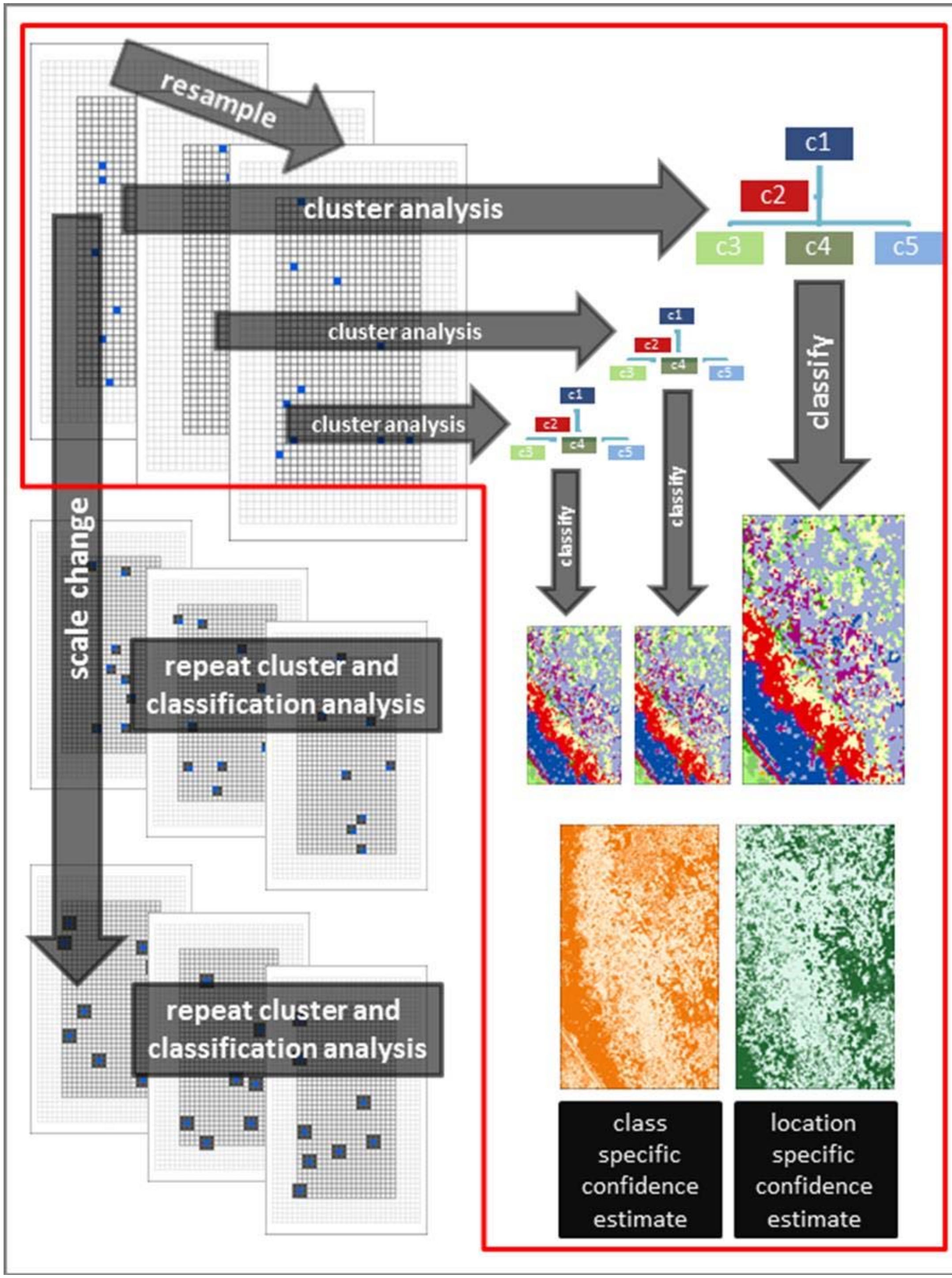
- allows for evaluation of stability of class descriptors

stability criteria

(1) distribution of optimal number of clusters for all sampling intensities of interest

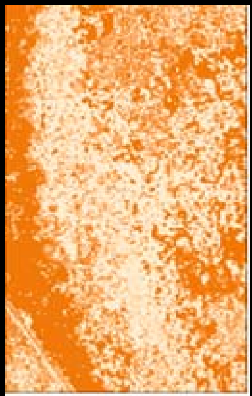
(2) class-specific model-based error estimates and class-specific classification probabilities of sites that had not been included in the clustering and classifier establishment routine

(3) spatially explicit (site-specific) distribution of mean and standard deviation of membership probability and consistency of plant association label assignment



Re-sampling at different scales

- allows for defining and evaluation of class descriptors at different spatial scales



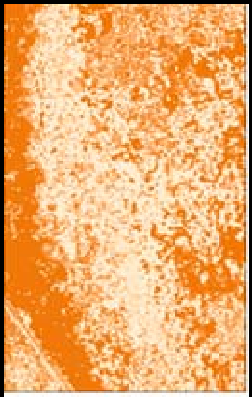
class specific confidence estimate

Results

number of optimal vegetation clusters (SS = 50, 200)
4.5 ±1.2 (mean ± SD);
4.1 ± 0.4

mean diversity of final clusters (SS = 50, 100, 150, 200)
8.8 ± 1.3 species
12.6 ± 1.1 species
13.9 ± 1.1 species
15.0 ± 1.1 species

model-based classification error for random forest classifiers (SS = 50, 100, 150, 200)
12.2 ± 8.3
7.2 ± 3.4
5.9 ± 2.6
5.8 ± 2.3



class specific confidence estimate

Results

number of optimal vegetation clusters (SS = 50, 200)
4.5 ±1.2 (mean ± SD); 4.1 ± 0.4

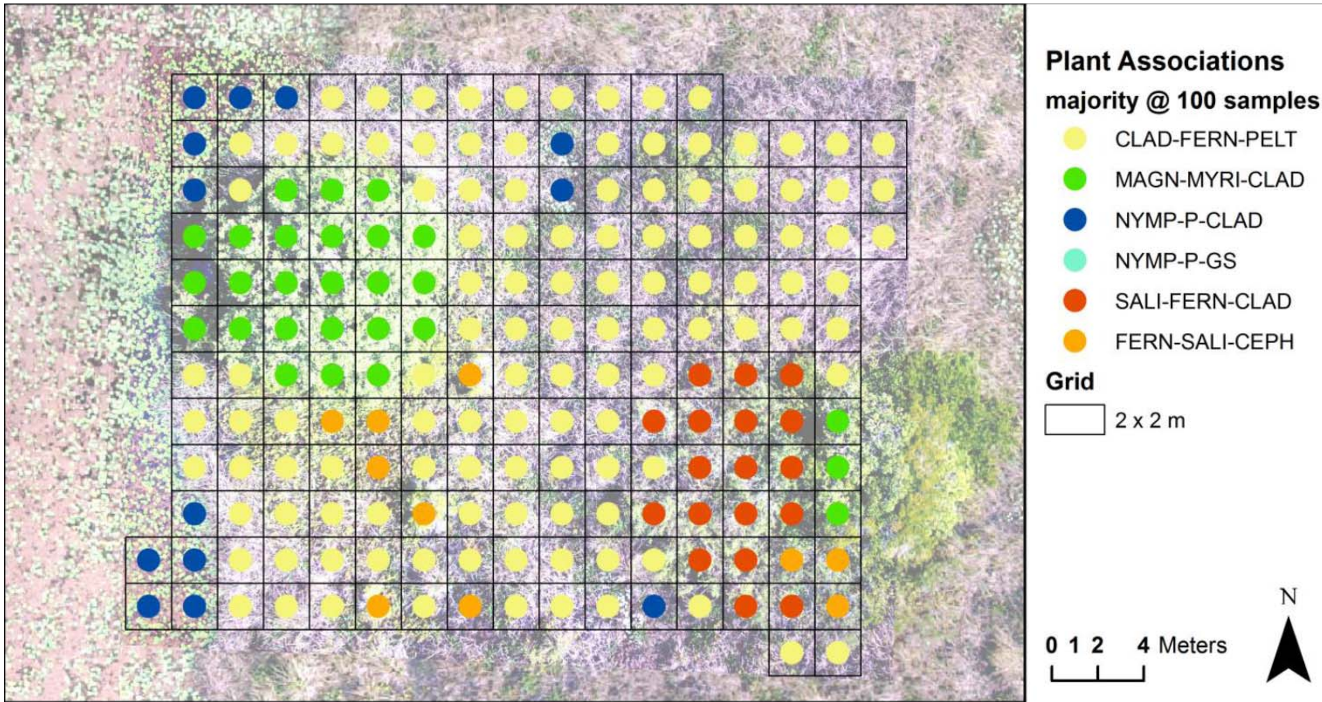
mean diversity of final clusters (SS = 50, 100, 150, 200)
8.8 ± 1.3; 12.6 ± 1.1; 13.9 ± 1.1; 15.0 ± 1.1 species

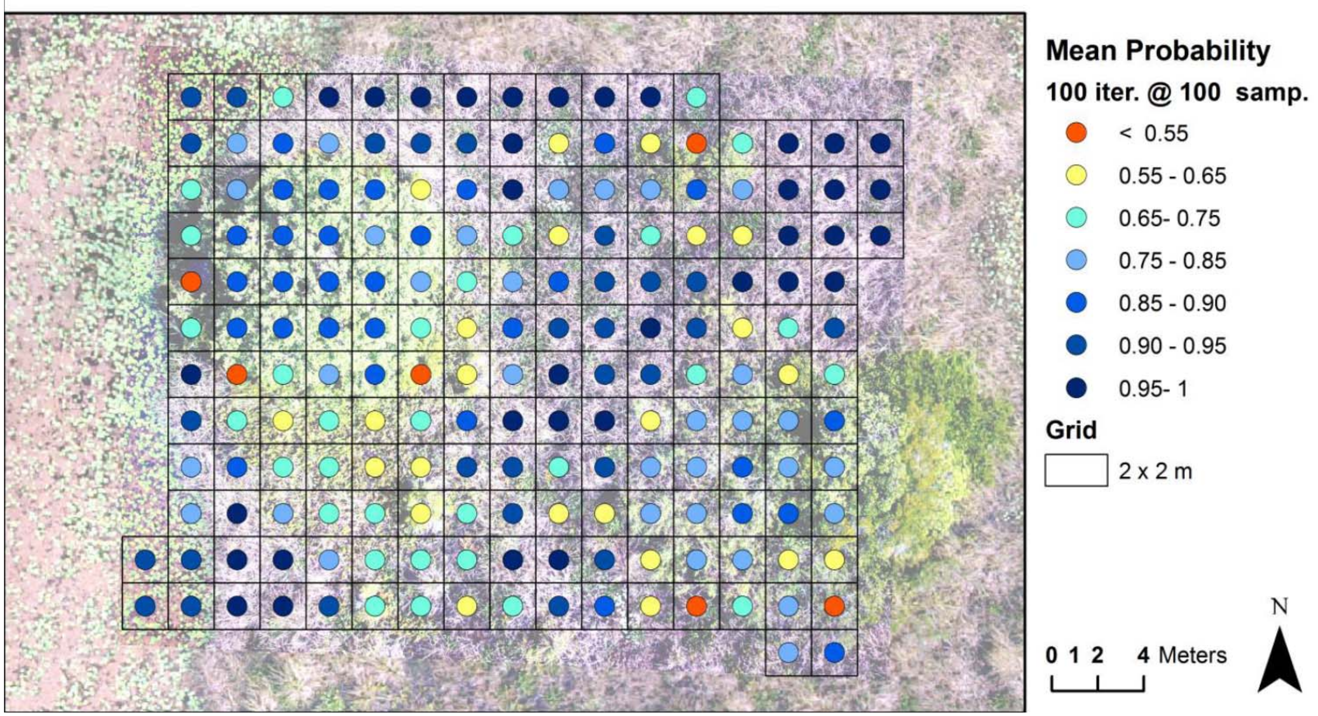
model-based classification error for random forest classifiers (SS = 50, 100, 150, 200)
12.2 ± 8.3; 7.2 ± 3.4; 5.9 ± 2.6; 5.8 ± 2.3

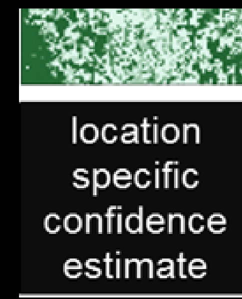
most frequently detected plant associations across all sampling intensities
Cladium-Fern-Peltandra (76.5%)
Nymphaea-Periphyton-Cladium (40%)
Fern-Salix-Cephalanthus (18.5%)
Nymphaea-Periphyton-Utricularia (18.0%)
Salix-Fern-Cladium (18.5%)
most abundant tree association
Magnolia-Myrica-Cladium (11%)

mean association assignment probability (Mn Prob) of the four most frequently occurring plant associations (SS = 50, 100, 150, 200)

Plant Association	Mn Prob (50)	Mn Prob (100)	Mn Prob (150)	Mn Prob (200)
Cladium-Fern-Peltandra	0.82	0.88	0.9	0.92
Magnolia-Cladium-Myrica	0.66	0.6	0.86	0.91
Nymphaea-Periphyton-Cladium	0.74	0.81	0.83	0.88
Fern-Salix-Cephalanthus	0.84	0.83	0.73	0.65







Results

image 550

plant associations derived from 100 cluster and classification iterations based on a sampling intensity of 100 samples per iteration (top panel). Location-specific mean probabilities for assigned plant association labels were determined from the 100 iterations (bottom panel)

Cladium-Fern-Peltandra (CLAD-FERN-PELT)
Magnolia-Myrica-Cladium (MAGN-MYRI-CLAD)
Nymphaea-Periphyton-Cladium (NYMP-P-CLAD)
Nymphaea-Periphyton-Graminoid Short (NYMP-P-GS)
Salix-Fern-Cladium (SALI-FERN-CLAD)
Fern-Salix-Cephalanthus (FERN-SALI-CEPH)

Results

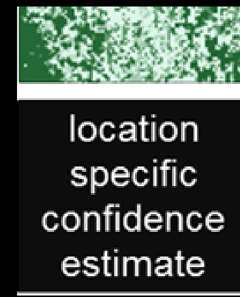
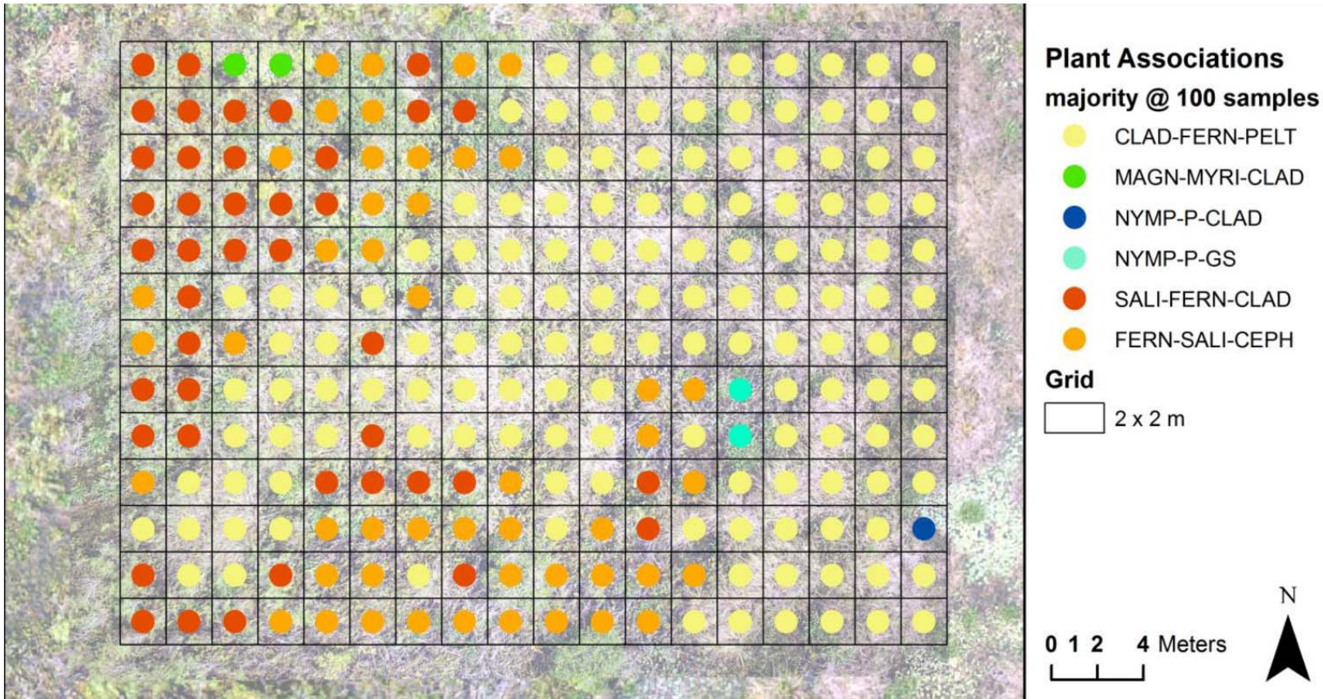
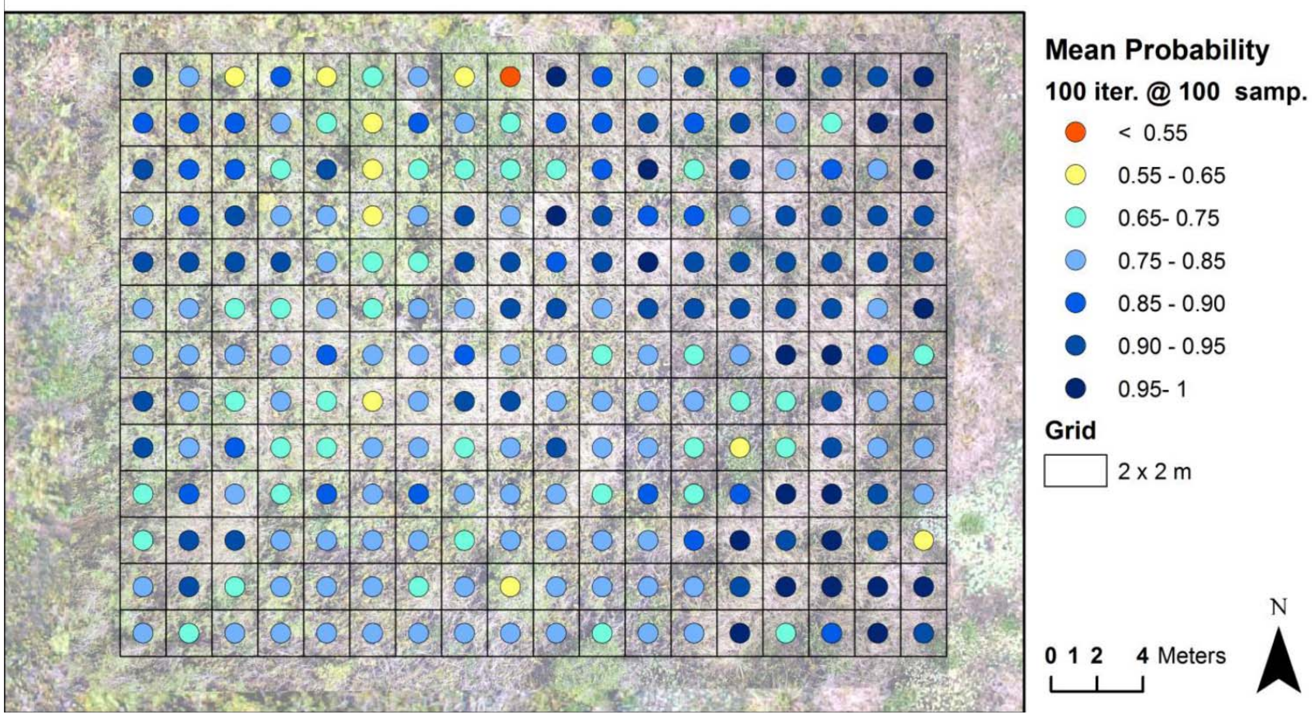


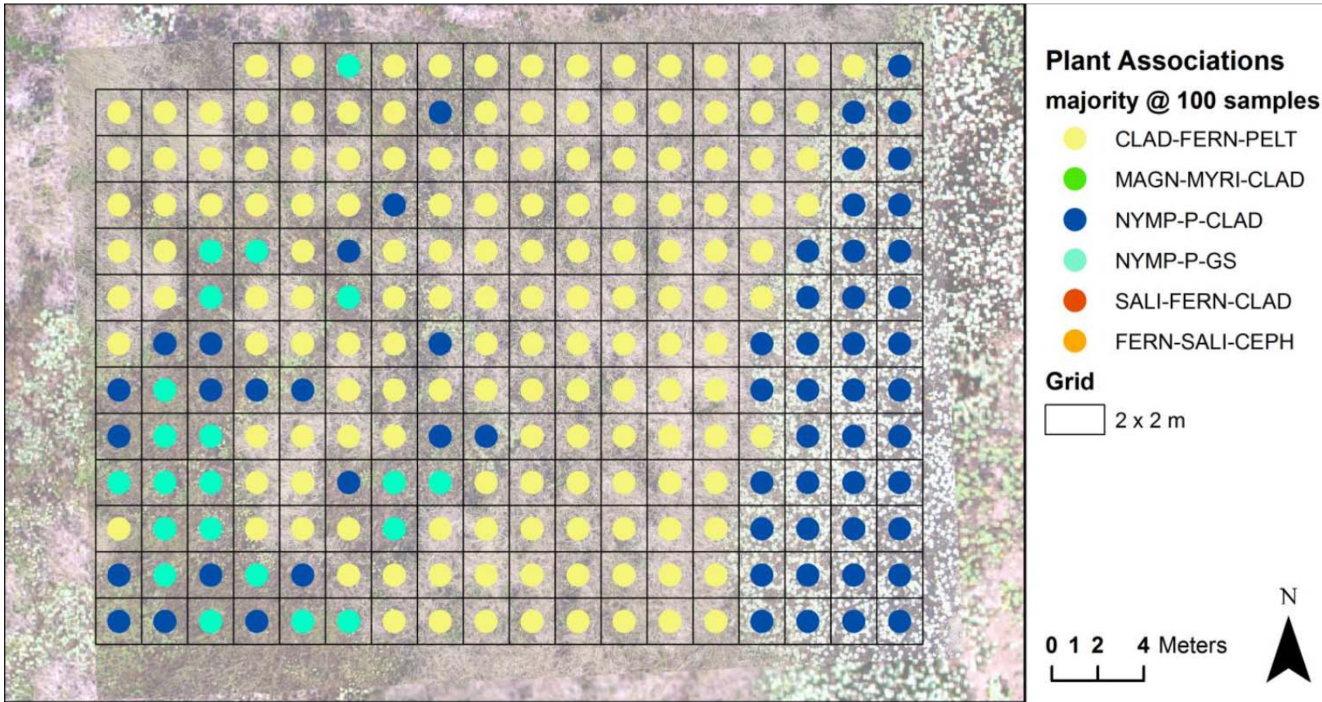
image 513

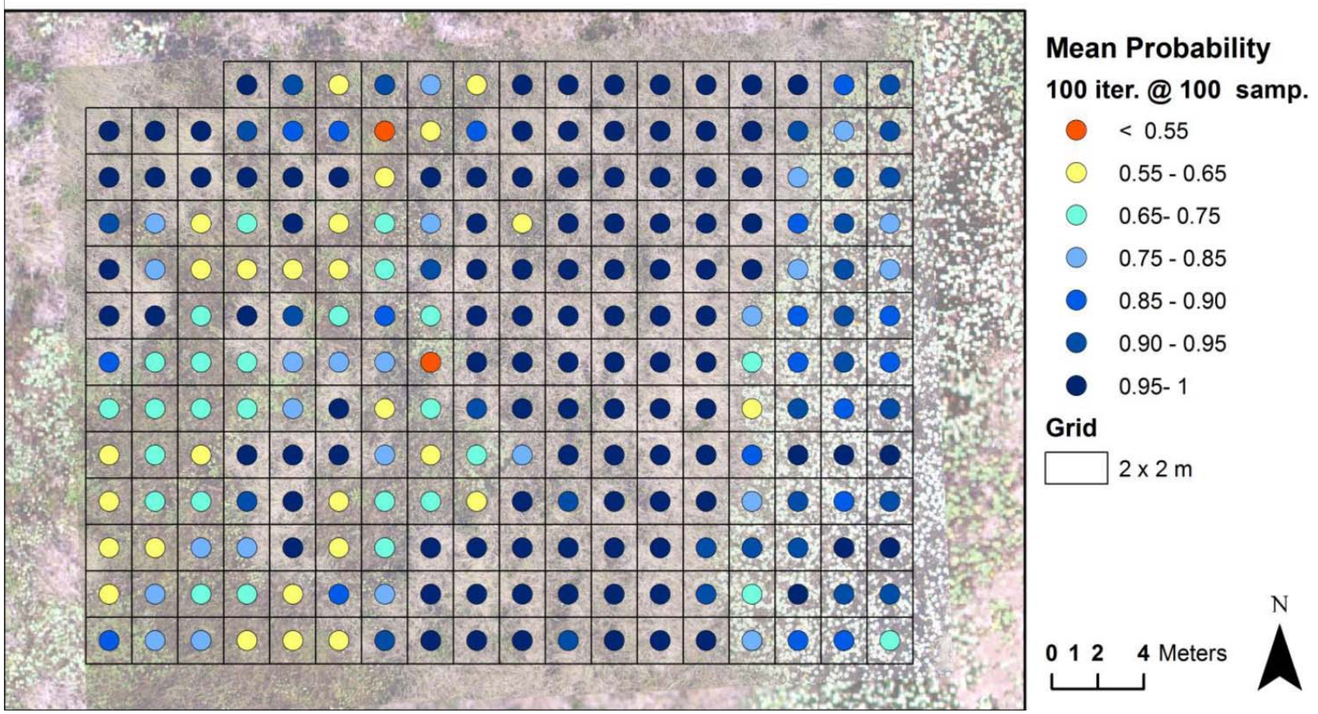


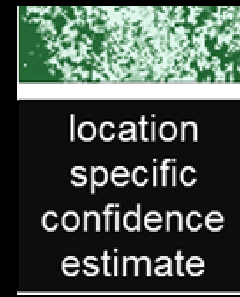


plant associations derived from 100 cluster and classification iterations based on a sampling intensity of 100 samples per iteration (top panel). Location-specific mean probabilities for assigned plant association labels were determined from the 100 iterations (bottom panel)

Cladium-Fern-Peltandra (CLAD-FERN-PELT)
Magnolia-Myrica-Cladium (MAGN-MYRI-CLAD)
Nymphaea-Periphyton-Cladium (NYMP-P-CLAD)
Nymphaea-Periphyton-Graminoid Short (NYMP-P-GS)
Salix-Fern-Cladium (SALI-FERN-CLAD)
Fern-Salix-Cephalanthus (FERN-SALI-CEPH)







Results

image 557

plant associations derived from 100 cluster and classification iterations based on a sampling intensity of 100 samples per iteration (top panel). Location-specific mean probabilities for assigned plant association labels were determined from the 100 iterations (bottom panel)

Cladium-Fern-Peltandra (CLAD-FERN-PELT)
Magnolia-Myrica-Cladium (MAGN-MYRI-CLAD)
Nymphaea-Periphyton-Cladium (NYMP-P-CLAD)
Nymphaea-Periphyton-Graminoid Short (NYMP-P-GS)
Salix-Fern-Cladium (SALI-FERN-CLAD)
Fern-Salix-Cephalanthus (FERN-SALI-CEPH)

Conclusion

Demonstrated how spatially continuous abundance data derived from hrAP can be used to establish and evaluate consistent and stable plant association classification systems

hrAP is extremely useful for deriving plant association classifications because

- enables estimation of class- and site-specific membership probability distributions and associated parameters
- confidence building and stability assessment of plant associations derived from samples is needed when attempting to detect associations from remotely sensed data
- application of association classifications to larger areas or entire regions is only valid if stability and consistency are confirmed
- use of hrAP allows for instantaneous visual feedback on adequacy of associations that results from cluster analysis
- multivariate statistical methods (i.e., clustering) have a tendency to provide multiple statistically reasonable solutions that can be highly variable but are caused by minor differences in parameter selection (parameter sensitive)

Conclusion

- Re-sampling framework enables visual and statistical evaluation of plant associations before they are used in detection and mapping applications using remote sening

- Iterative visual validation coupled with statistical validity of association classifications over large areas guides the clustering parameter adjustment

- Clustering parameters need to be revisited and adjusted
  - minimum number of classes that are expected as sampling intensity increases - decrease in optimal number of clusters based on within and between cluster variances (the Calinski-Harabasz criterion) might not be the most useful criterion, especially if cluster sizes are expected to differ as much as they do in the case of our study area
  - optimization of cluster count is based on the minimal number of supported cluster solutions excluding single species associations → at the 2 m grain size, pure classes need to be permitted, especially for large tree species.