Estimating basal area, trees, and above ground biomass per acre for common tree species across the Uncompahgre Plateau using NAIP CIR imagery

By

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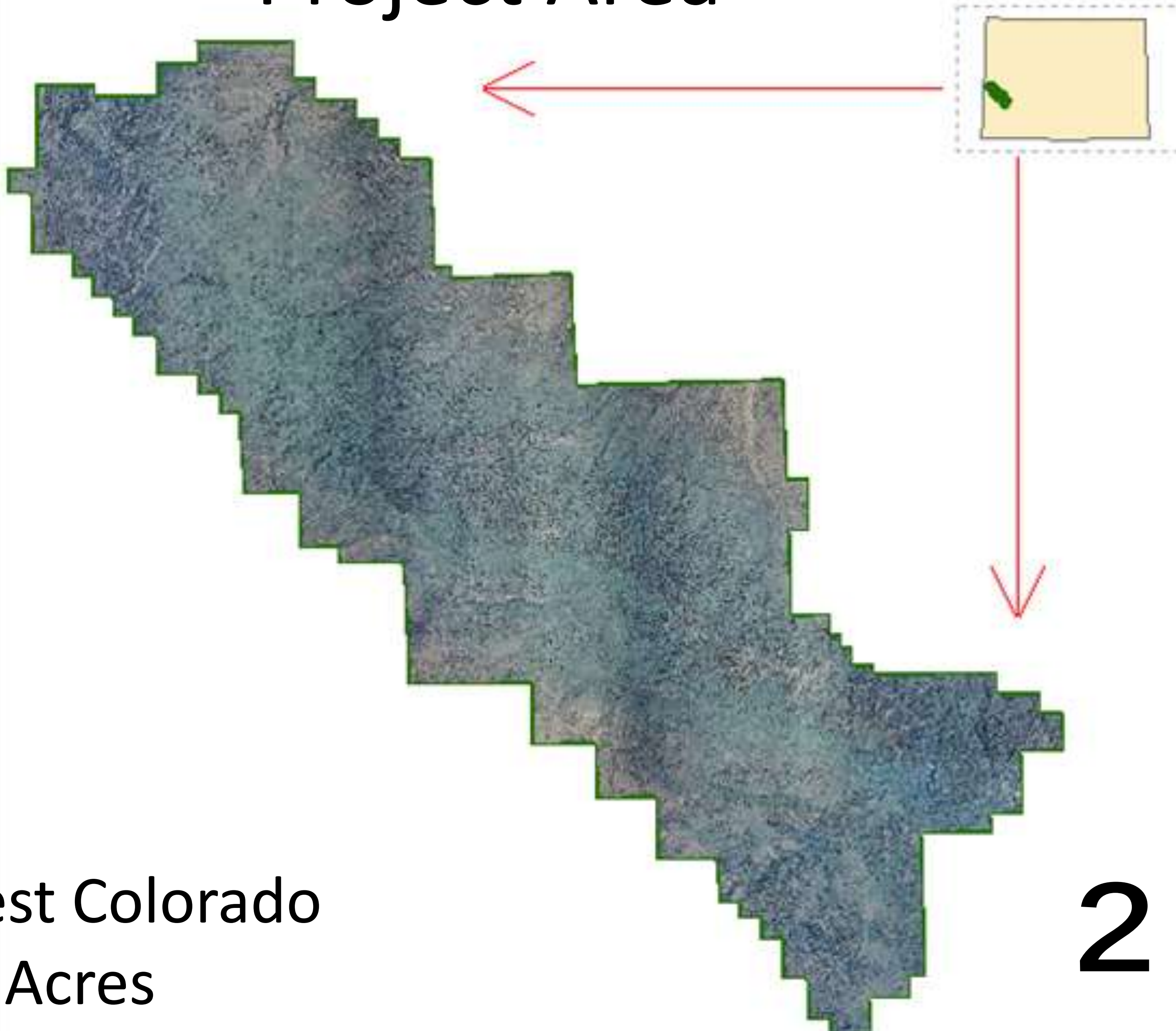
Objective

- Develop a flexible and transferable methodology to estimate basal area per acre, trees per acre, and above ground biomass per acre
  - Use consistent and readily available data sources
  - Generate outputs that can be used to model multiple management scenarios
  - Fine grained detail ($1m^2$)

Project Area



Southwest Colorado
580,000 Acres

Major Tree Species

- Quaking Aspen
- Ponderosa Pine
- Lodge Pole
- Subalpine Fir
- Corkbark Fir
- Douglass Fir
- Engelmann Spruce
- Blue Spruce
- Pinyon Pine
- Rocky Mountain Juniper
- Utah Juniper
- Mountain Mahogany
- Gambel Oak

Tree Species Groups

- Quaking Aspen
- Ponderosa Pine
- Lodge Pole
- Subalpine Fir
- Corkbark Fir
- Douglass Fir
- Engelmann Spruce
- Blue Spruce

Aspen

Pine

Spruce/Fir

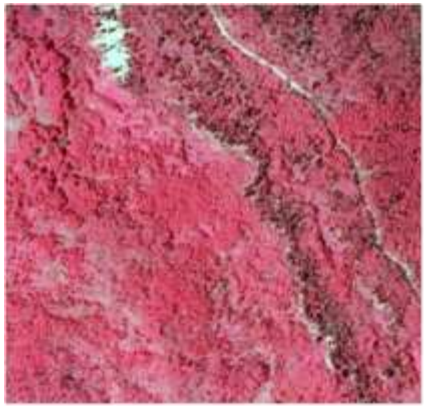
- Pinyon Pine
- Rocky Mountain Juniper
- Utah Juniper
- Mountain Mahogany
- Gambel Oak

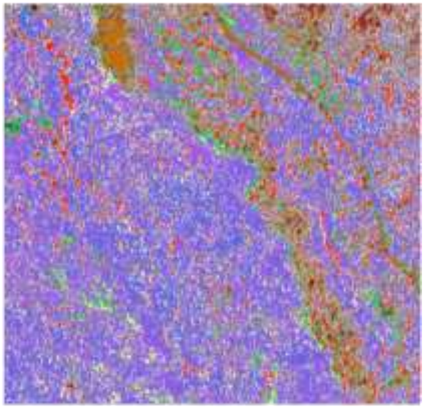
Pinyon/Juniper

Shrubs

Datasets

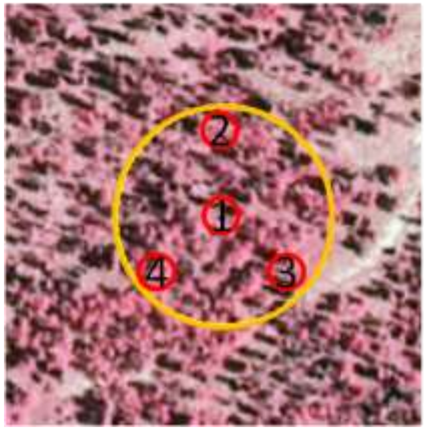
- Imagery
  - NAIP (CIR)
  - DEM ?





- Stratified Random sample
  - Visually interpreted from imagery

- Field Data
  - Plot data (FIA)
  - Fixed radius



2 Stage Approach

- Probabilistic classification using Polytomous Logistic Regression (grain size 1 m)
  - Identifying tree species groups using spectral bands and texture
- Multivariate Regression (BAA, TPA, and AGB)
  - Window Circle with radius of 7 meters -> FIA plot size
    - Develop texture metrics that quantify trees vs. open ground/shadow for the probabilistic classification

2 Stage Approach

- **Probabilistic classification** using Polytomous Logistic Regression (grain size 1 m)
  - Identifying tree species groups using spectral bands and **texture**
- Multivariate Regression (BAA, TPA, AGB)
  - Window Circle with radius of 44 meters -> FIA plot size
    - Develop **texture** metrics that quantify trees vs. open ground/shadow for the **probabilistic classification**

Maximum Likelihood Classification (Discriminant function analysis)

$$\mathrm{MD} = D_j(i) = (\mathbf{x}_\mathrm{i} - \bar{\mathbf{x}})' \mathbf{S}^{-1} (\mathbf{x}_i - \bar{\mathbf{x}}) \qquad \mathrm{i} = 1, \ldots, \mathrm{n} \qquad \mathrm{j} = 1, \ldots, \mathrm{p}$$

$$\mathrm{QDS} = D_j(i) = -\frac{1}{2} \ln |\mathbf{S}_j| - \frac{\mathbf{1}}{\mathbf{2}} (\mathbf{x}_i - \bar{\mathbf{x}}_j)' \mathbf{S}_j^{-1} (\mathbf{x}_i - \bar{\mathbf{x}}_j) + \ln p_j \qquad \begin{array}{c} j = 1, \ldots, n \\ p_j = \textit{prior for class } j \end{array}$$

$$PP(j \mid i) = \frac{\exp\left(-\frac{1}{2} D_j(i)\right)}{\sum_{i=1}^{j} \exp\left(-\frac{1}{2} D_j(i)\right)}$$

where $\mathbf{x}_i$ and $\bar{\mathbf{x}}$ are the observed vector and mean vector, respectively, and **S** and $\mathbf{S}_j$ are the pooled sampled covariance matrix and the sample covariances, respectively (Johnson and Wichern, 2002).

Polytomous logistic regression

Estimated class (response) probabilities $\{\pi_j(x)\}$ are determined by manipulating baseline category logits as follows:

given $\sum_j \pi_j(\mathbf{x}) = 1, \quad j = 1,\ldots,J\text{-}1, \qquad \pi_J(\mathbf{x}) = 1 - \sum_{h=1}^{J-1} \pi_h(\mathbf{x}).$

$$\ln\left(\frac{\pi_j(\mathbf{x})}{\pi_J(\mathbf{x})}\right) = \mathbf{x}'\boldsymbol{\beta}_j \qquad \mathbf{x}' = [1, \quad \mathbf{x}'_i] \quad \mathrm{i} = 1,\ldots \mathrm{p}$$

$$\pi_j(\mathbf{x}) = \frac{\exp(\mathbf{x}'\boldsymbol{\beta}_j)}{1 + \sum_{h=1}^{J-1} \exp(\mathbf{x}'\boldsymbol{\beta}_h)} \qquad \pi_J(\mathbf{x}) = \frac{1}{1 + \sum_{h=1}^{J-1} \exp(\mathbf{x}'\boldsymbol{\beta}_h)}$$

Where $\pi_j(\mathbf{x})$ is the mean probability of group j, with class means and variances equal to $n\pi_j$ and $n\pi_j(1-\pi_j)$, respectively (Agresti, 2002).

Texture

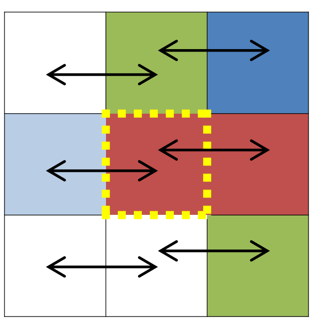
First Order

0	1	9
7	8	8
0	0	1

Summary statistics of all neighboring pixels (N = 9)

$$P_{i,j} = \frac{V_{i,j}}{\sum_{i,j=0}^{N-1} V_{i,j}}$$

Second Order Grey-Level Co-occurrence Matrix (GLCM)



Summary statistics of all pixel/neighbor pixel relationships in a given direction (Horizontal or Vertical; N = 12)

J \ I	0	1	2	3	4	5	6	7	8	9
0	2	2	0	0	0	0	0	0	0	0
1	2	0	0	0	0	0	0	0	0	1
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	1	0
8	0	0	0	0	0	0	0	1	2	0
9	0	1	0	0	0	0	0	0	0	0

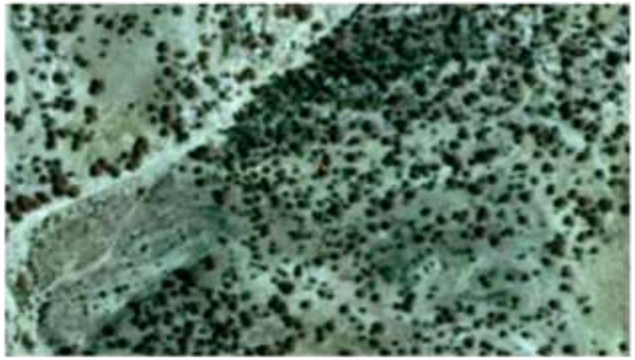
(Haralick, 1979)

Texture GLCM

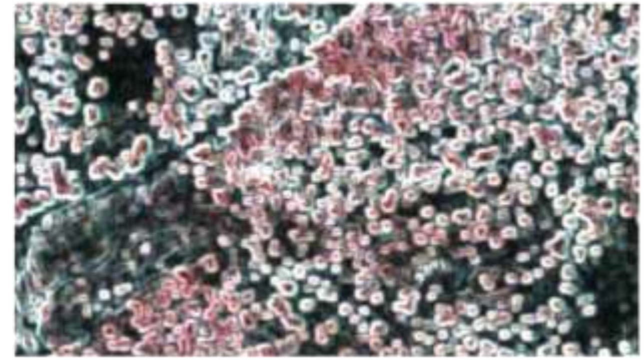
- Contrast $\sum_{i,j=0}^{N-1} P_{i,j}(i-j)^2$
- Dissimilarity $\sum_{i,j=0}^{N-1} P_{i,j}|i-j|$
- Homogeneity $\sum_{i,j=0}^{N-1} \frac{P_{i,j}}{1+(i-j)^2}$
- Entropy $\sum_{i,j=0}^{N-1} P_{i,j}(-\ln(P_{i,j}))$
- Energy $\sqrt{\sum_{i,j=0}^{N-1} (P_{i,j})^2}$
- ASM $\sum_{i,j=0}^{N-1} (P_{i,j})^2$
- Mean $\sum_{i,j=0}^{N-1} i(P_{i,j})$
- Variance $\sum_{i,j=0}^{N-1} P_{i,j}(i-\mu_i)^2$
- Covariance $\sum_{i,j=0}^{N-1} P_{i,j}(i-\mu_i)(i-\mu_j)$
- Correlation $\sum_{i,j=0}^{N-1} P_{i,j}\left[\frac{(i-\mu_i)(j-\mu_j)}{\sqrt{\sigma_i^2 \times \sigma_j^2}}\right]$
- Max Probability $\max\{P_{i,j}\}$
- Min Probability $\min\{P_{i,j}\}$
- Range $\max - \min$

Texture

NAIP

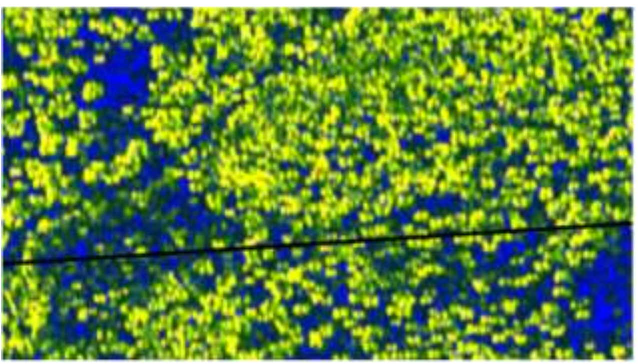


First Order STD

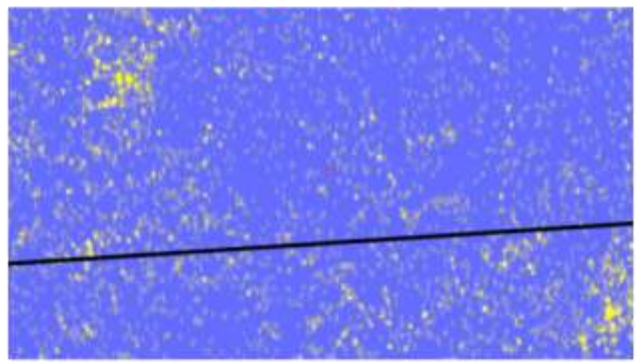


Second Order GLCM

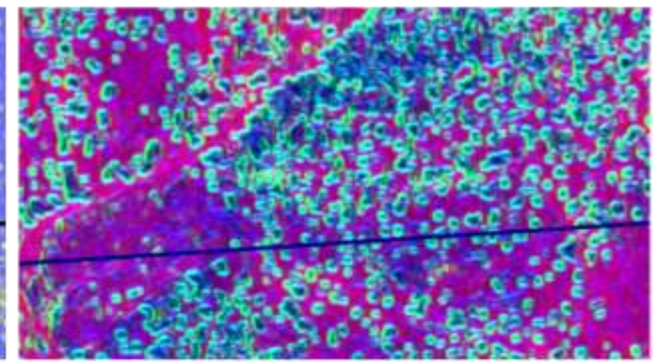
Contrast



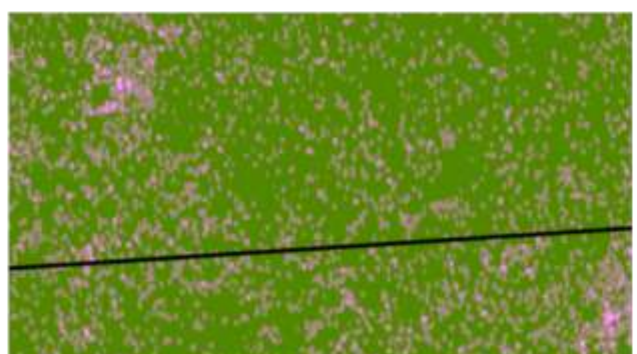
Orderliness



Statistics



Extremes

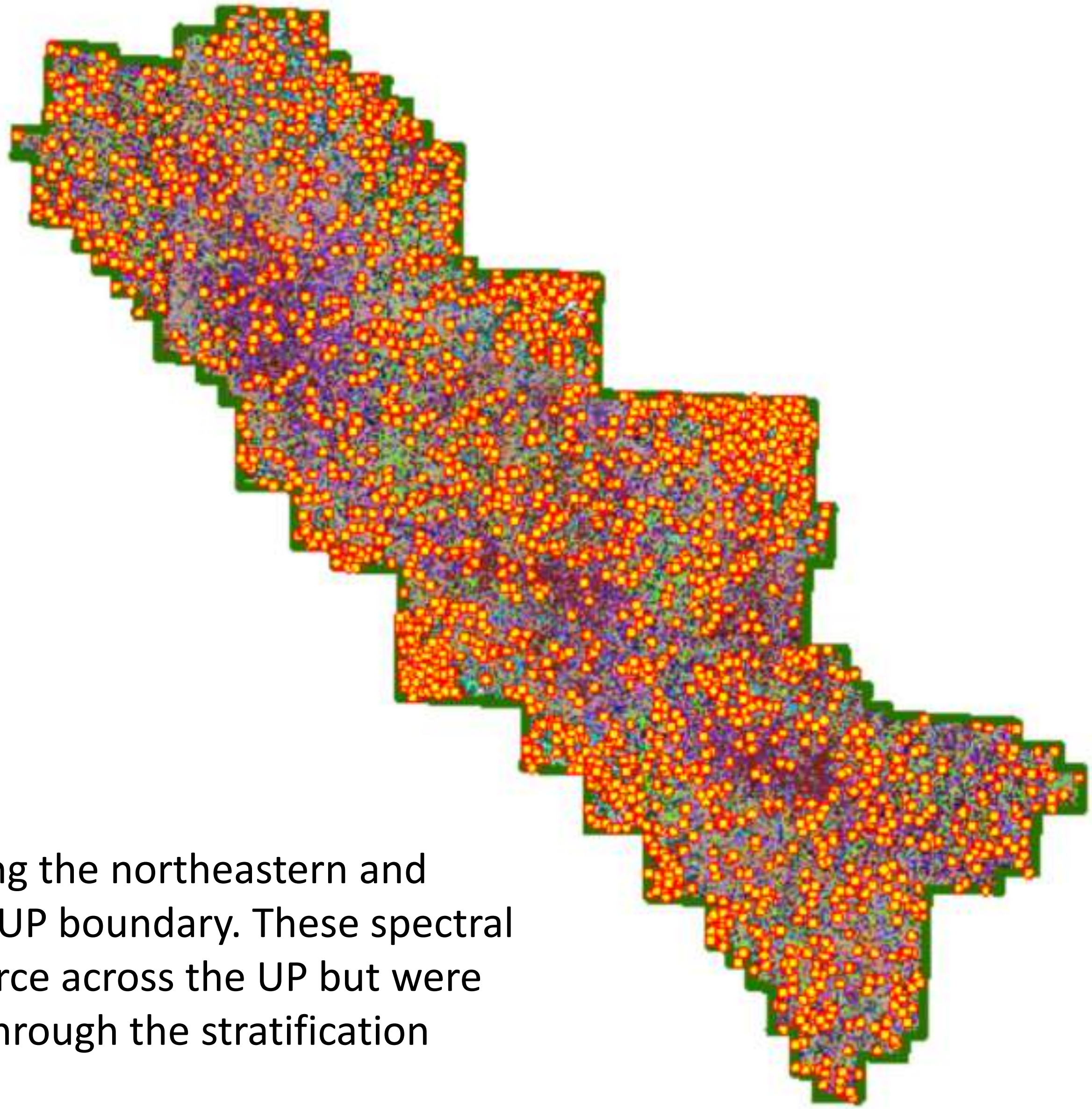


Stage 1
Probabilistic Classification

Methodology

- Create stratified random sample
  - ISO cluster
  - Randomly allocate sample locations
  - Visually interpret locations
- Create first order Standard Deviation of NAIP
- Ordinate NAIP and Standard Deviation
- Create GLCM
- Relate visually interpreted locations to ordination values and texture metrics
- Model species group probabilities

Stratified Random sample locations of 20 ISO spectral classes



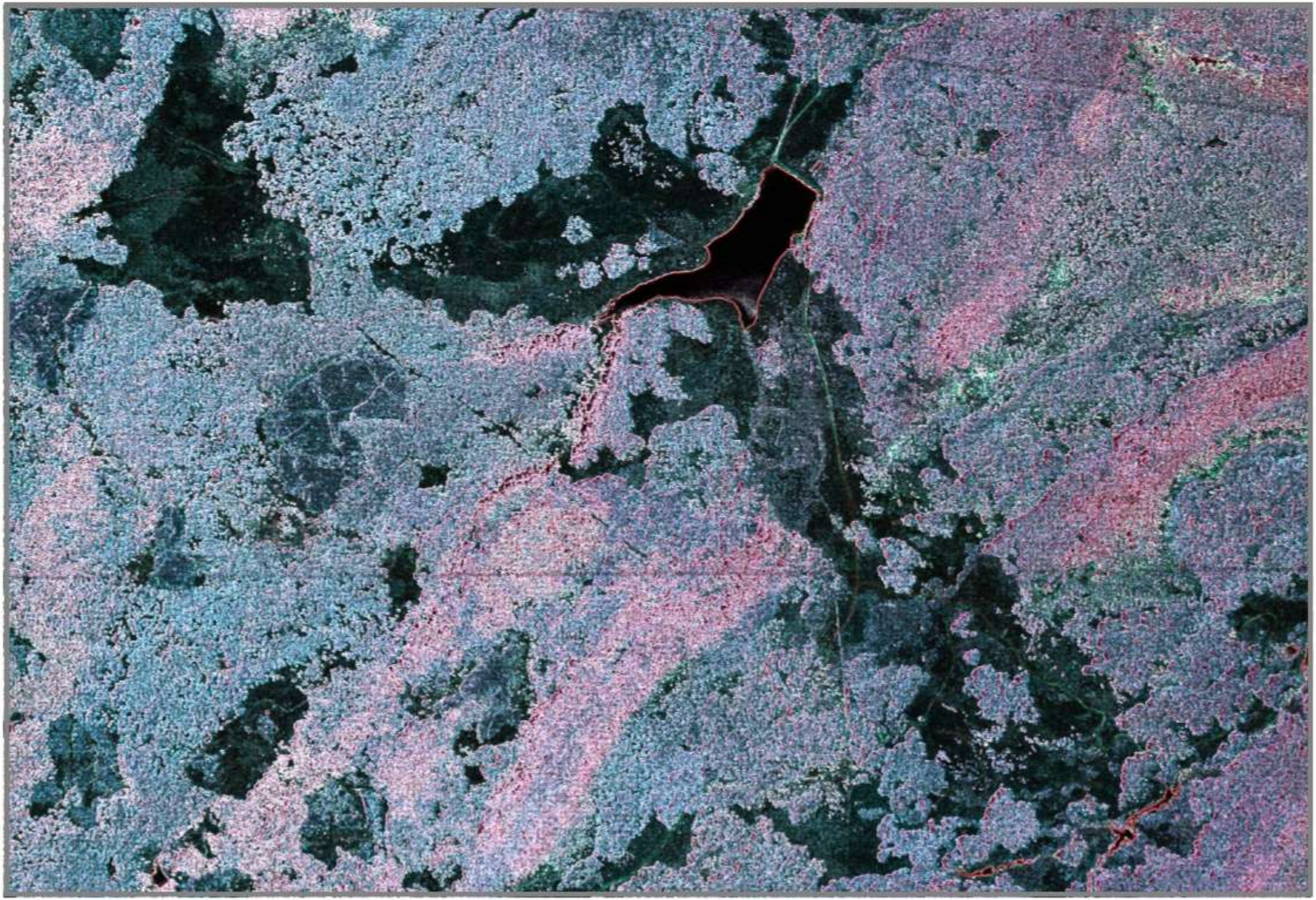
Note sample clustering along the northeastern and southwestern edges of the UP boundary. These spectral groups where relatively scarce across the UP but were represented in the model through the stratification process.

Area Subset

NAIP Color

NAIP Color Infrared (CIR)

Rescaled Standard Deviation (SD) of NAIP Color Infrared



Principle Components Analysis (PCA)

- Problem
  - NAIP CIR highly correlated among bands
  - SDs highly correlated with each other
  - Variables are not independent
- Objective
  - Reduce dimensionality
  - Create independent variables for modeling

PCA Results

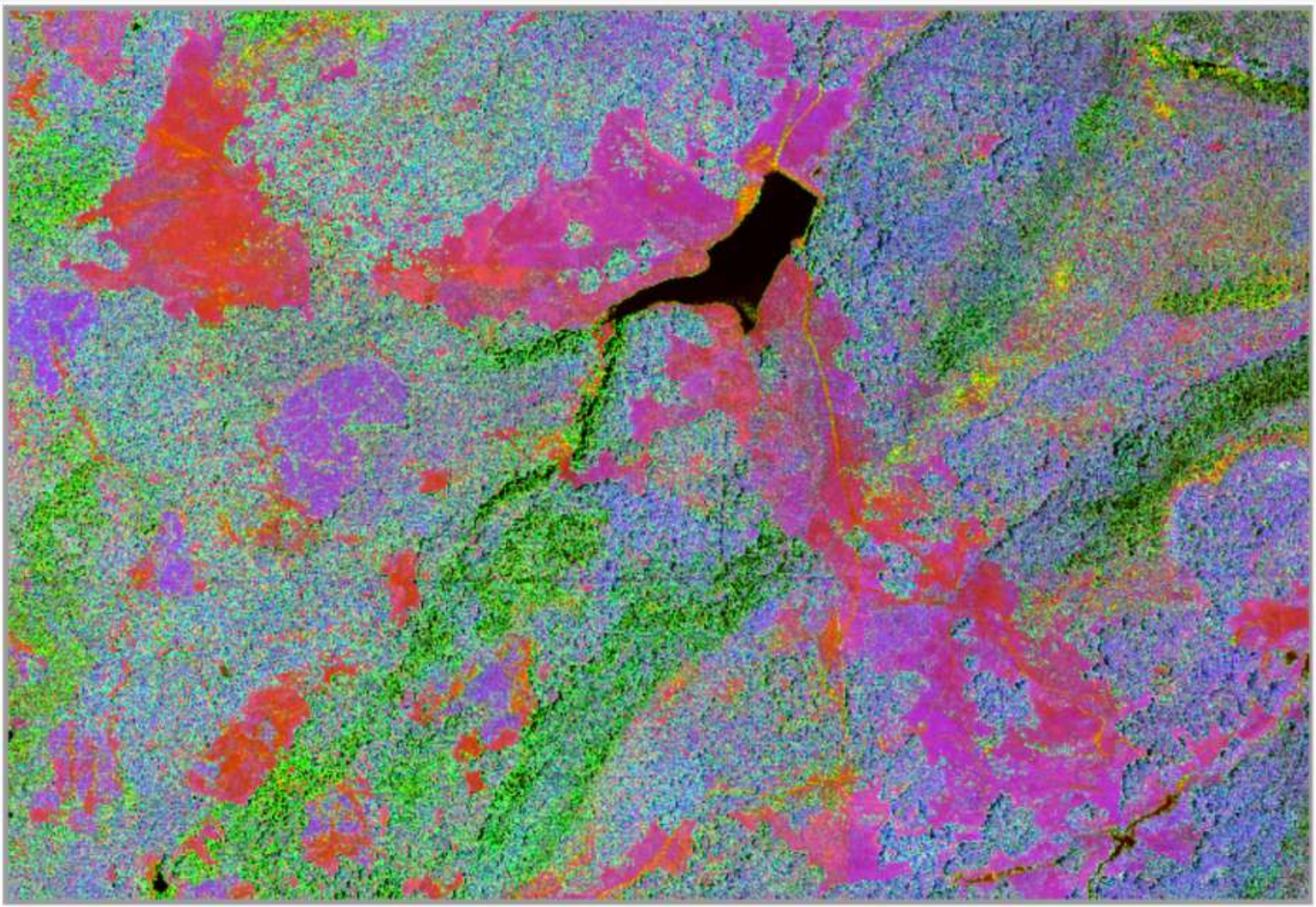
Eigen Values

Component	Eigen Value	Proportion	Cumulative
1	19580.01	64.03%	64.03%
2	7309.35	23.90%	87.94%
3	3236.85	10.59%	98.52%
4	234.59	0.77%	99.29%
5	166.53	0.54%	99.83%
6	51.10		100.00%

Eigen Vectors

Parameter	PC1	PC2	PC3	PC4	PC5	PC6
NAIP Band1	0.475	0.156	0.820	-0.077	0.266	0.012
NAIP Band2	0.608	0.174	-0.559	-0.241	0.469	-0.099
NAIP Band3	0.575	0.136	-0.098	0.402	-0.687	0.086
SD Band1	-0.170	0.446	-0.051	0.762	0.415	0.133
SD Band2	-0.138	0.594	-0.032	-0.412	-0.152	0.659
SD Band3	-0.163	0.613	0.040	-0.155	-0.203	-0.728

3 band color composite of Principle components 1, 2, and 3 for area subset



Quantified GLCM Texture

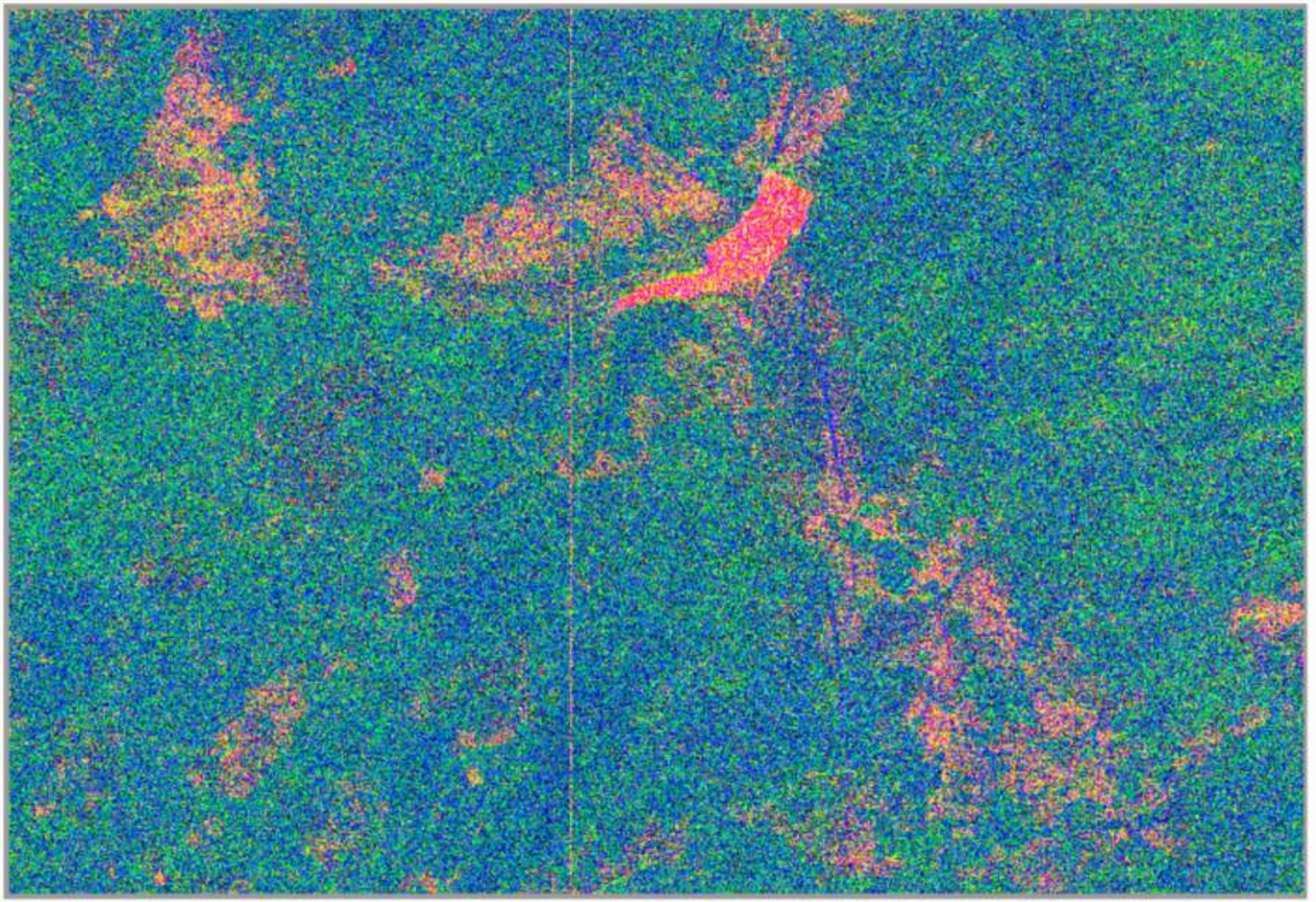
- Contrast
- Dissimilarity
- Homogeneity

- Entropy
- Energy
- ASM

- Mean
- Variance
- Covariance
- Correlation

- Max Probability
- Min Probability
- Range

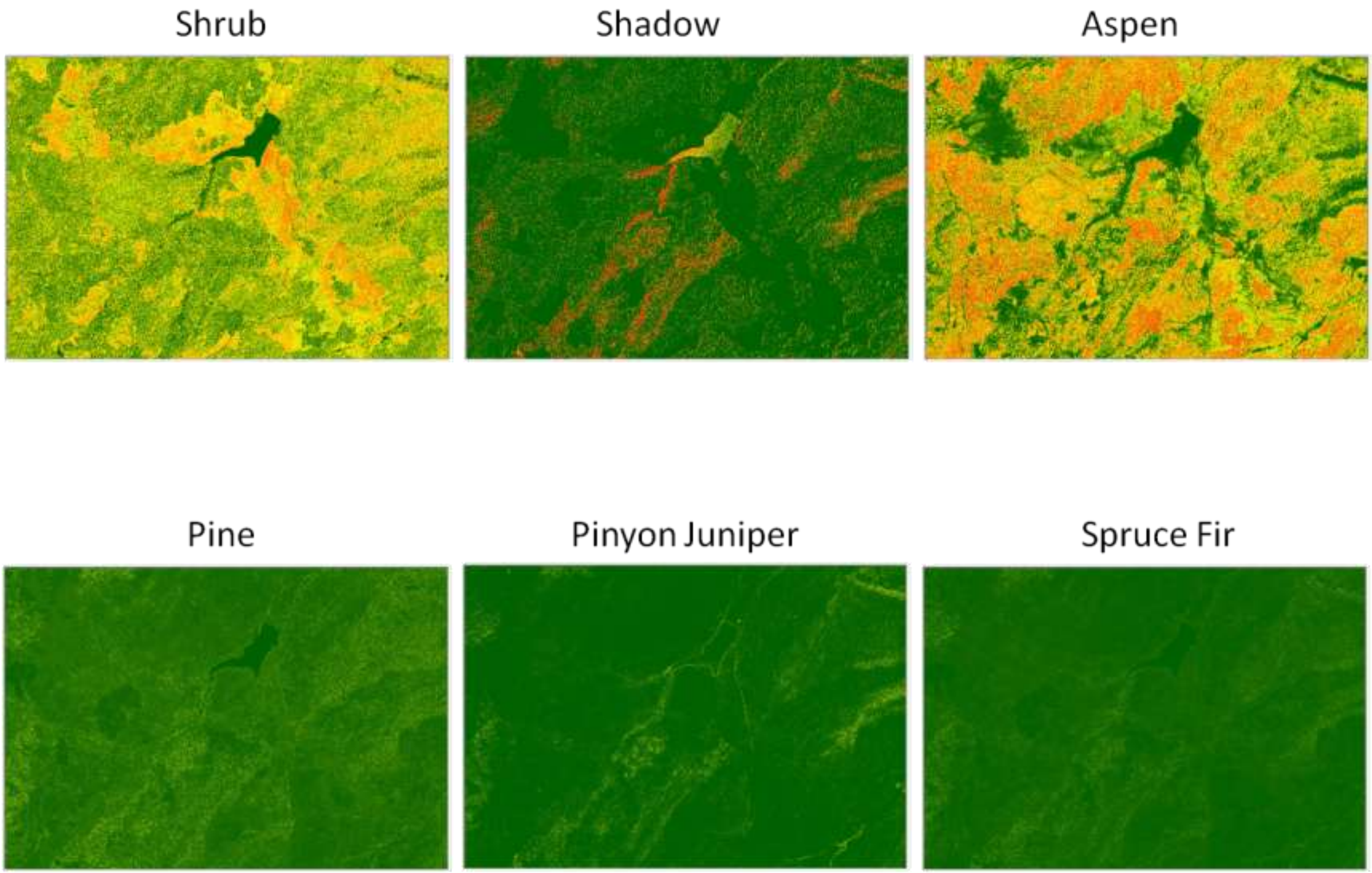
3 band color composite of Horizontal Homogeneity, Horizontal Correlation, and Vertical Correlation GLCM output from Brightness component (3*3 moving window)

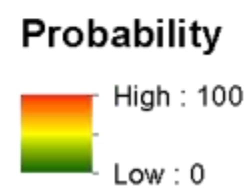


PLR Model Selection

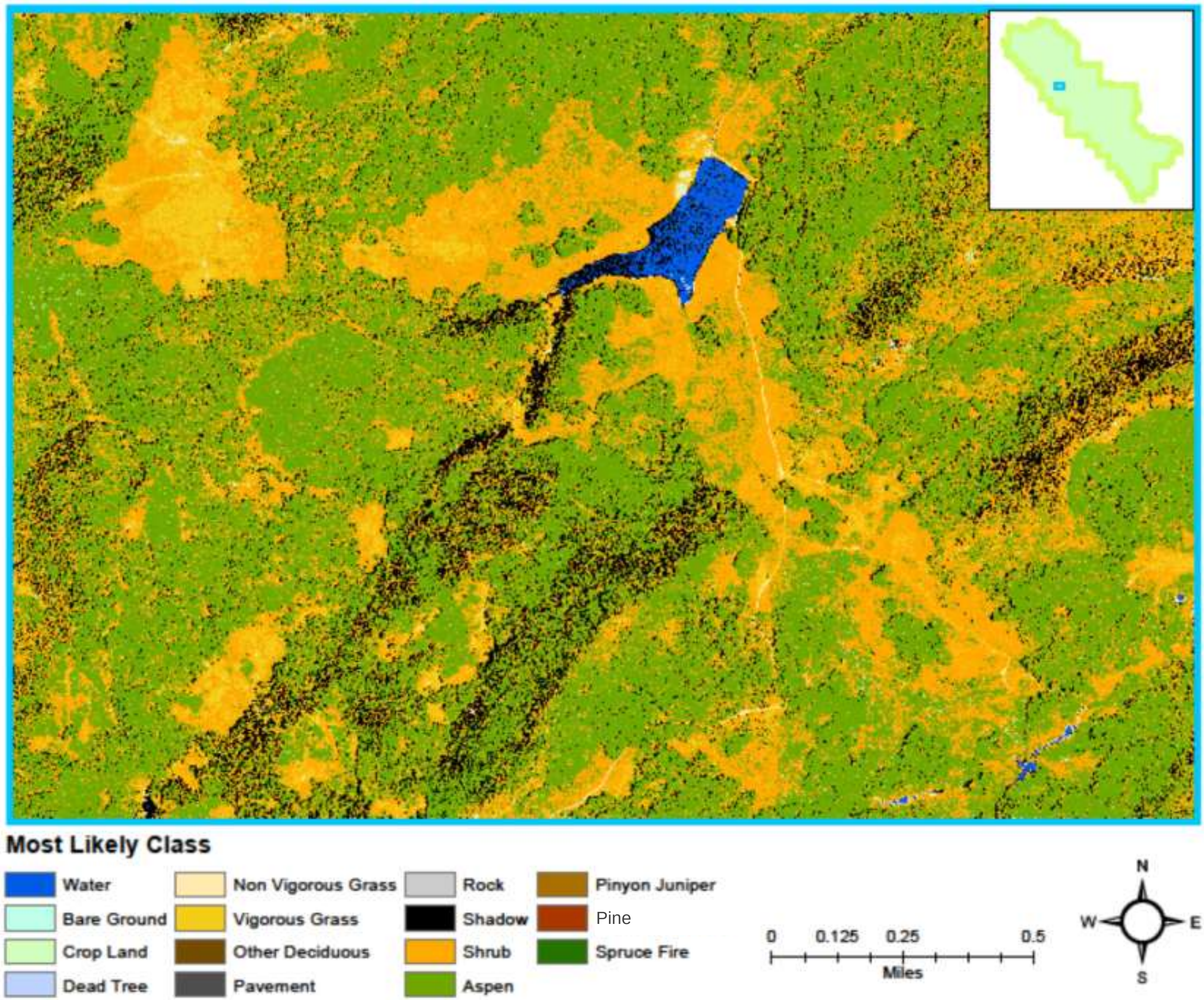
Rank	Parameters	DF	-2 Log Likelihood	AIC	ΔAIC
1	PC1-3, H_Ho, V_Corr, H_Corr, _H_Ho	98	4551.675	4775.675	17.581
2	PC1-3, H_Ho, V_Corr, H_Corr	84	4597.256	4793.256	3.224
3	PC1-3, H_Ho, V_Corr, H_Corr, _V_Var	98	4572.48	4796.48	8.764
4	PC1-3, V_Corr, H_Corr	70	4629.964	4805.244	1.786
5	PC1-3, H_Ho, V_Corr, H_Corr, _V_Corr	98	4583.03	4807.03	4.428
6	PC1, PC3, V_Ho, V_Corr, H_Corr, H_Con	84	4615.458	4811.458	2.77
7	PC1, PC3, V_Ho, H_Ho, V_Corr, H_Corr, V_Var	98	4590.228	4814.228	4.812
8	PC3, H_MEAN, V_Ho, V_Corr, H_Corr, H_Con	84	4623.04	4819.04	NA

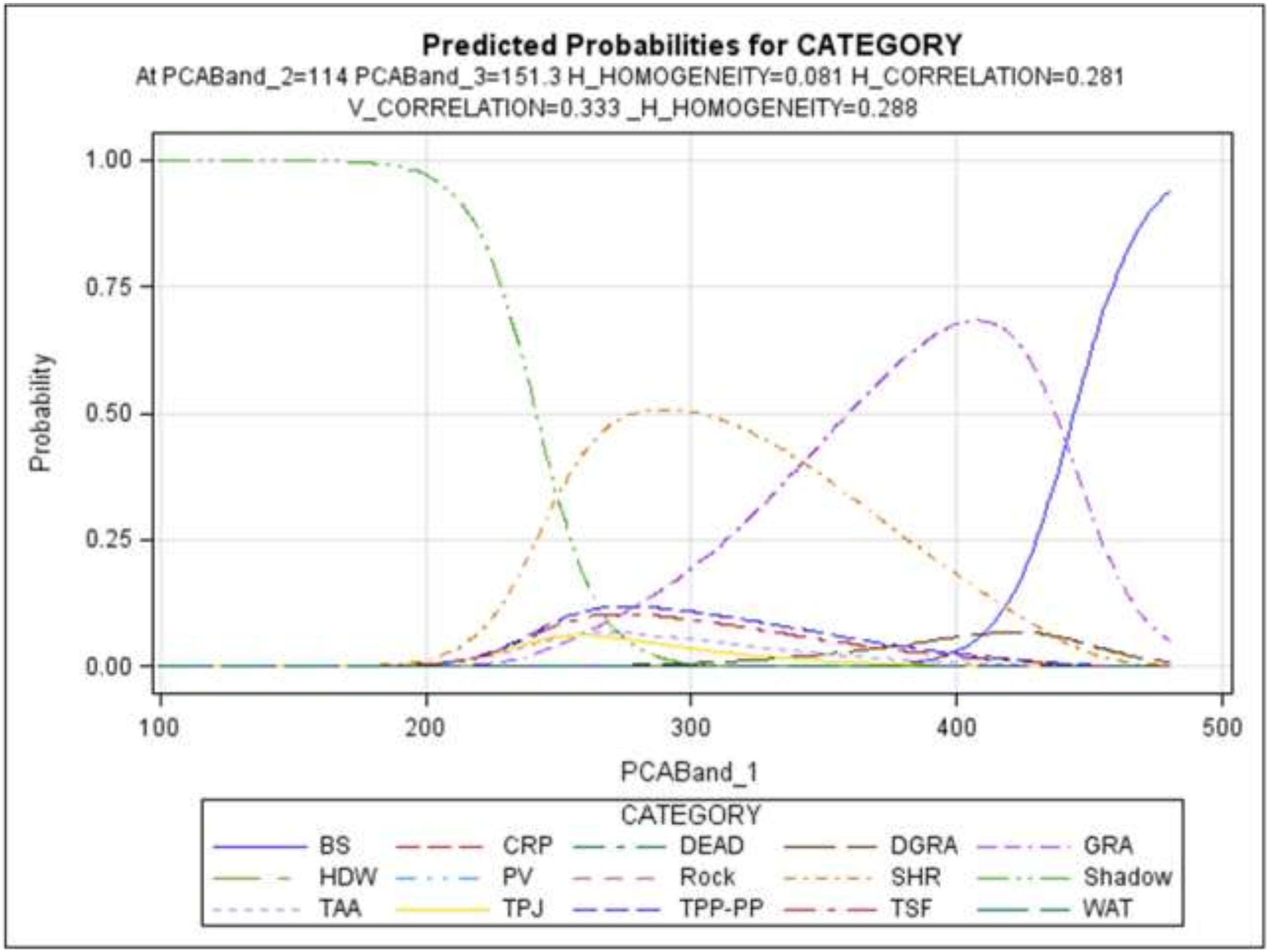
Outputs



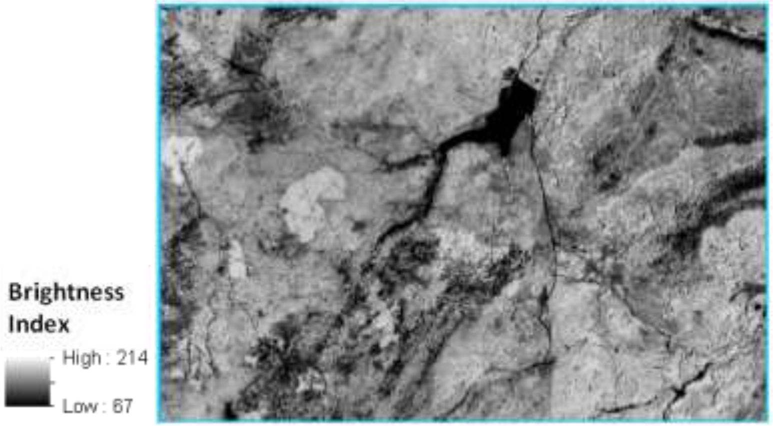


An example of the probabilistic surfaces created from PLR model

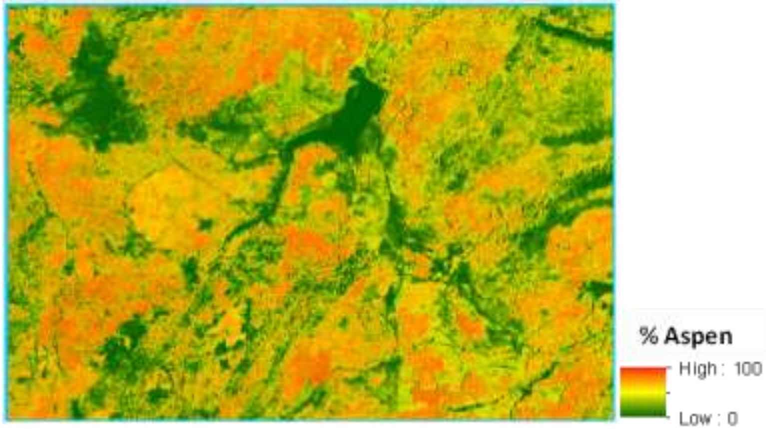

Most Likely Class
Water
Bare Ground
Crop Land
Dead Tree
Non Vigorous Grass
Vigorous Grass
Other Deciduous
Pavement
Rock
Shadow
Shrub
Aspen
Pinyon Juniper
Pine
Spruce Fire
0
0.125
0.25
0.5
Miles
N
W
E
S



Predicted Probabilities for CATEGORY
At PCABand_2=114 PCABand_3=151.3 H_HOMOGENEITY=0.081 H_CORRELATION=0.281
V_CORRELATION=0.333 _H_HOMOGENEITY=0.288
Probability
1.00
0.75
0.50
0.25
0.00
100
200
300
400
500
PCABand_1
CATEGORY
BS
CRP
DEAD
DGRA
GRA
HDW
PV
Rock
SHR
Shadow
TAA
TPJ
TPP-PP
TSF
WAT



Brightness Index
High : 214
Low : 67



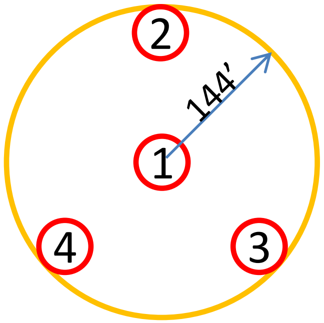
% Aspen
High : 100
Low : 0

Stage 2

BAA, TPA, & AGB

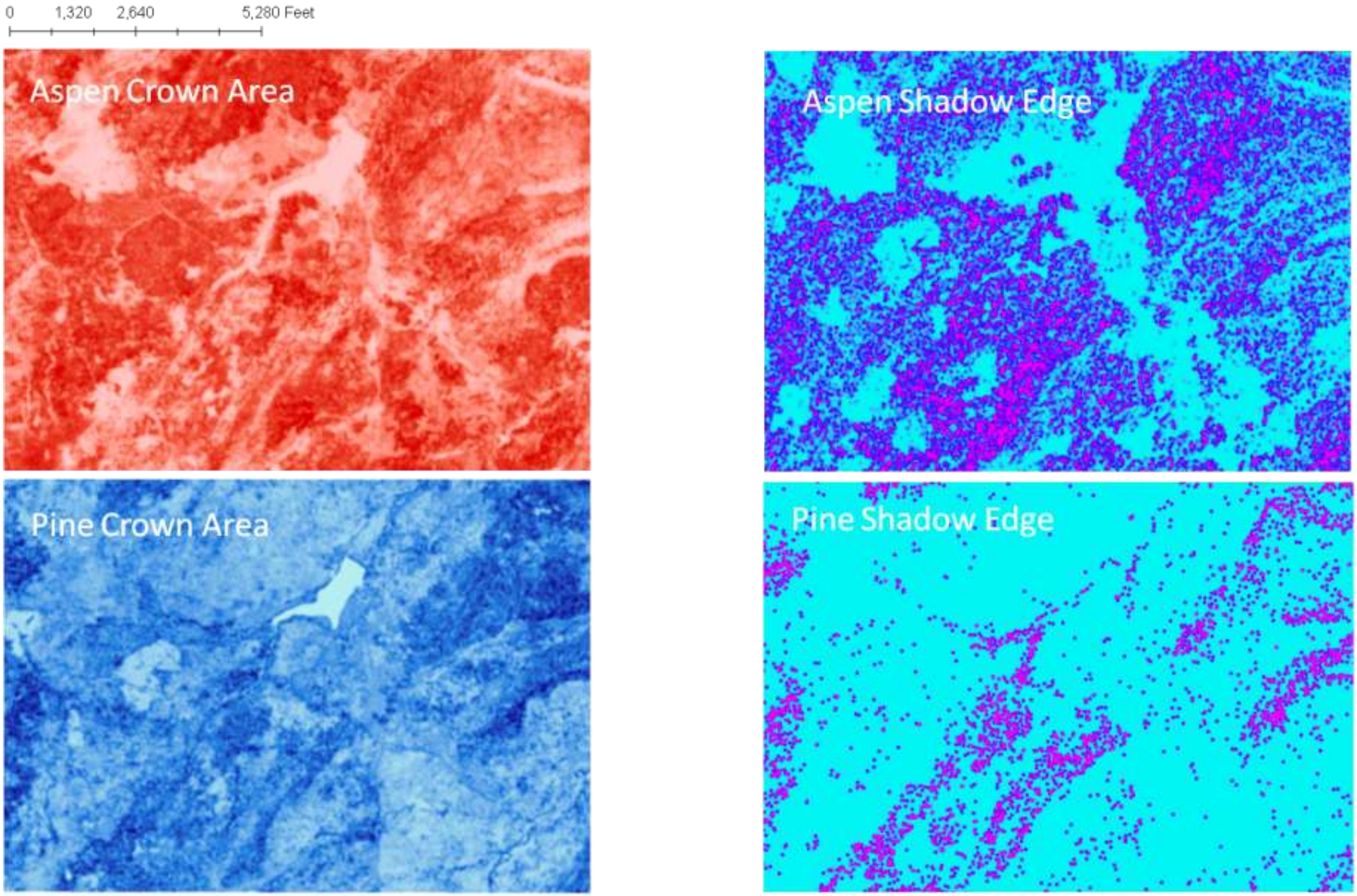
Methodology

- Create predictive variables
  - Probability texture metrics from stage 1 classification
  - Summarized GLCM texture metrics
  - Summarized PCA values
- Summarize FIA plot data (subplot)



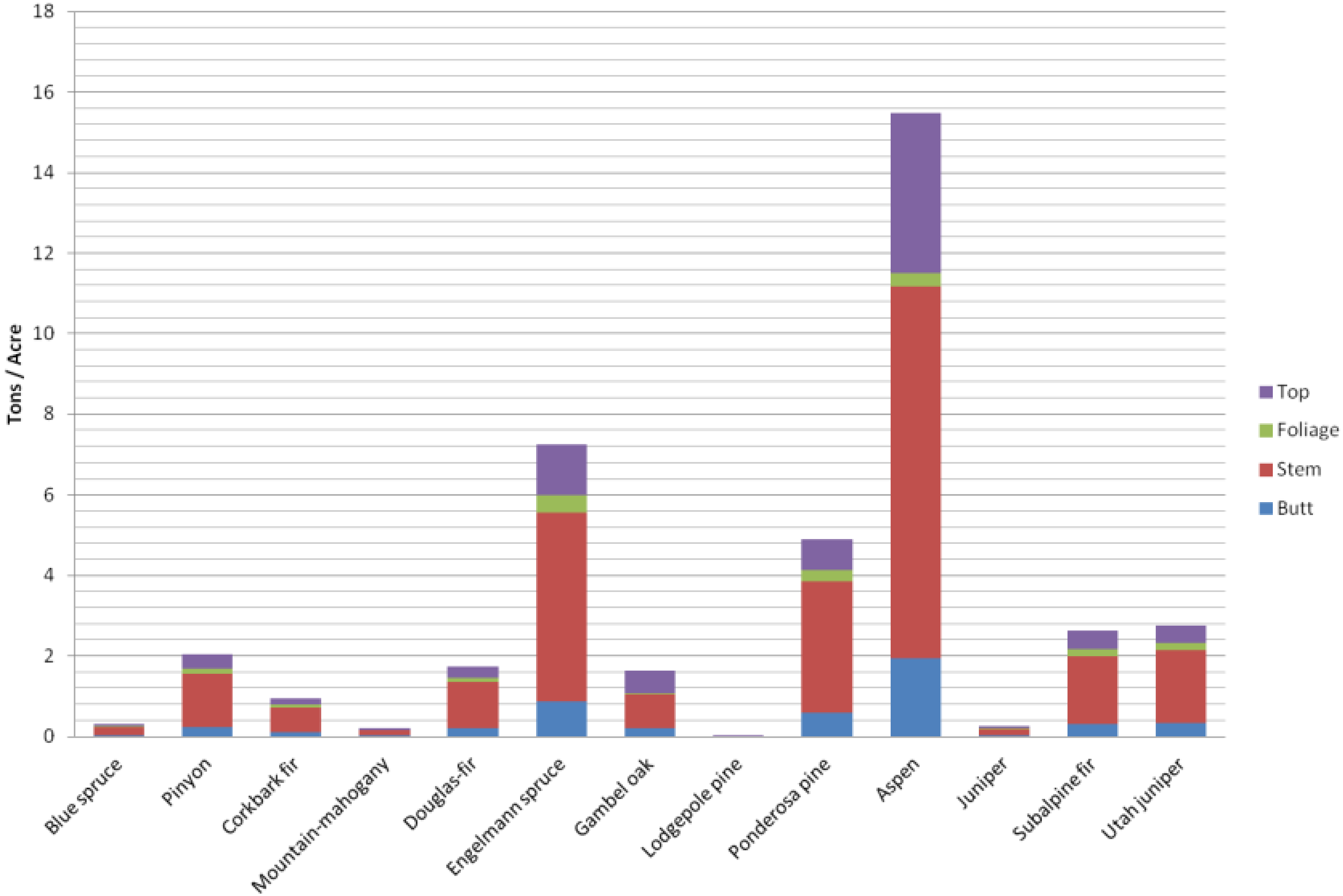
- Relate FIA plot data to Texture metrics
- Multivariate regression to estimate BAA, TPA, and AGB by species group

Probabilistic Texture



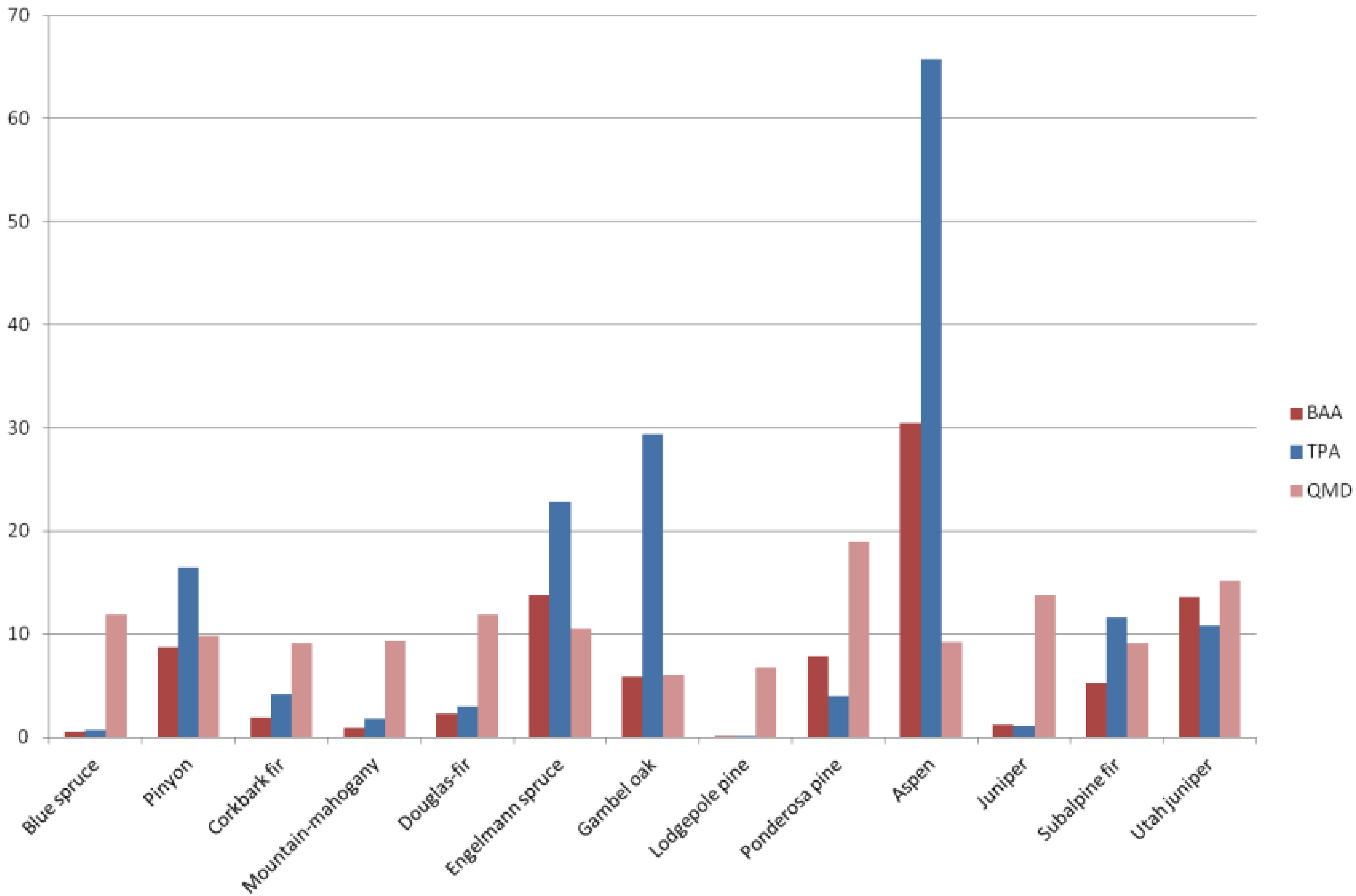
Summarized FIA Data

AGB FIA Plot Summary by Species

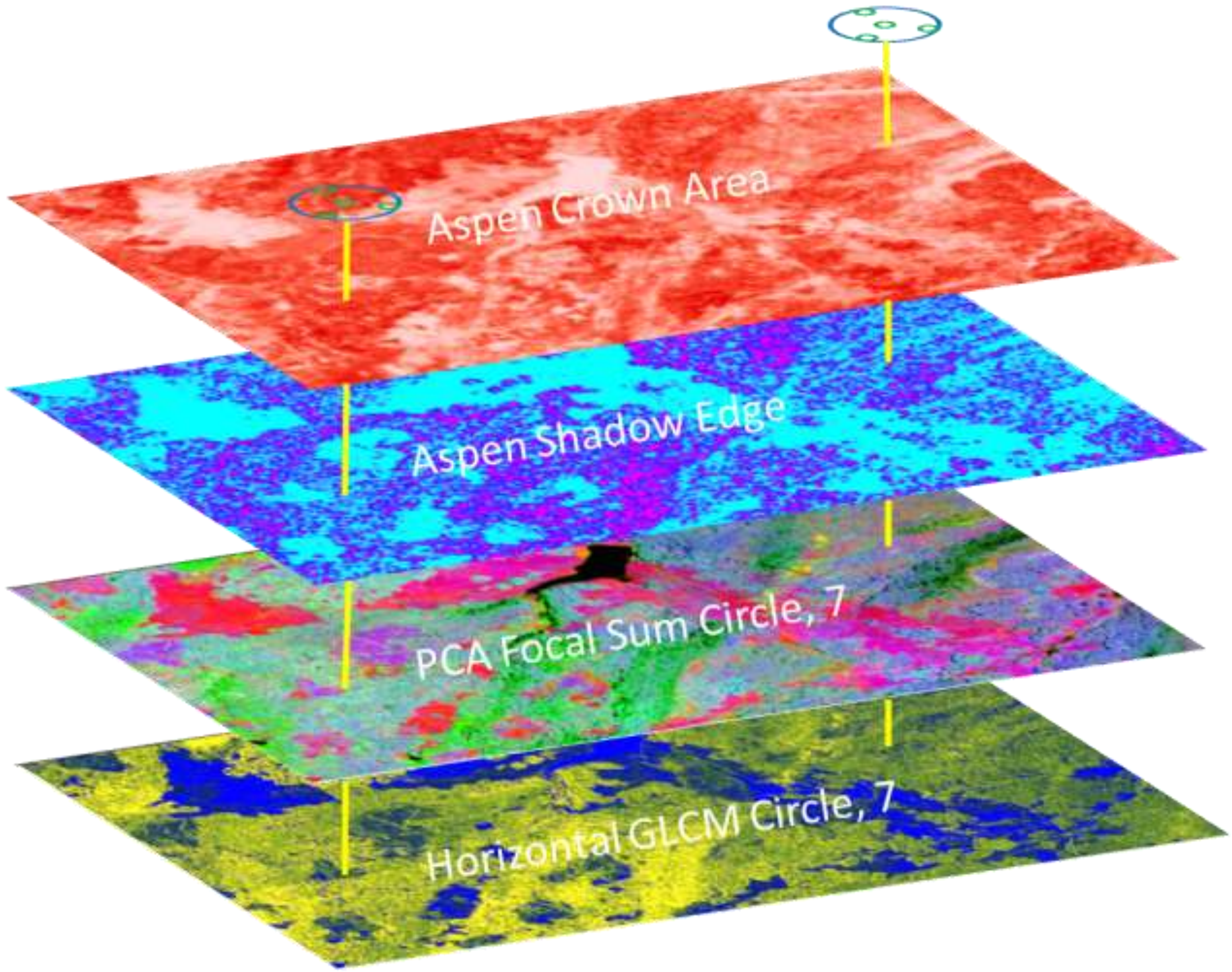


Summarized FIA Data

QMD, BAA, and TPA FIA Plot Summary by Species



Sample Metrics



Multivariate Regression

$$BAA_i = \alpha_i + \beta_i \mathrm{X}_j$$

$$TPA_i = \alpha_i + \beta_i \mathrm{X}_j$$

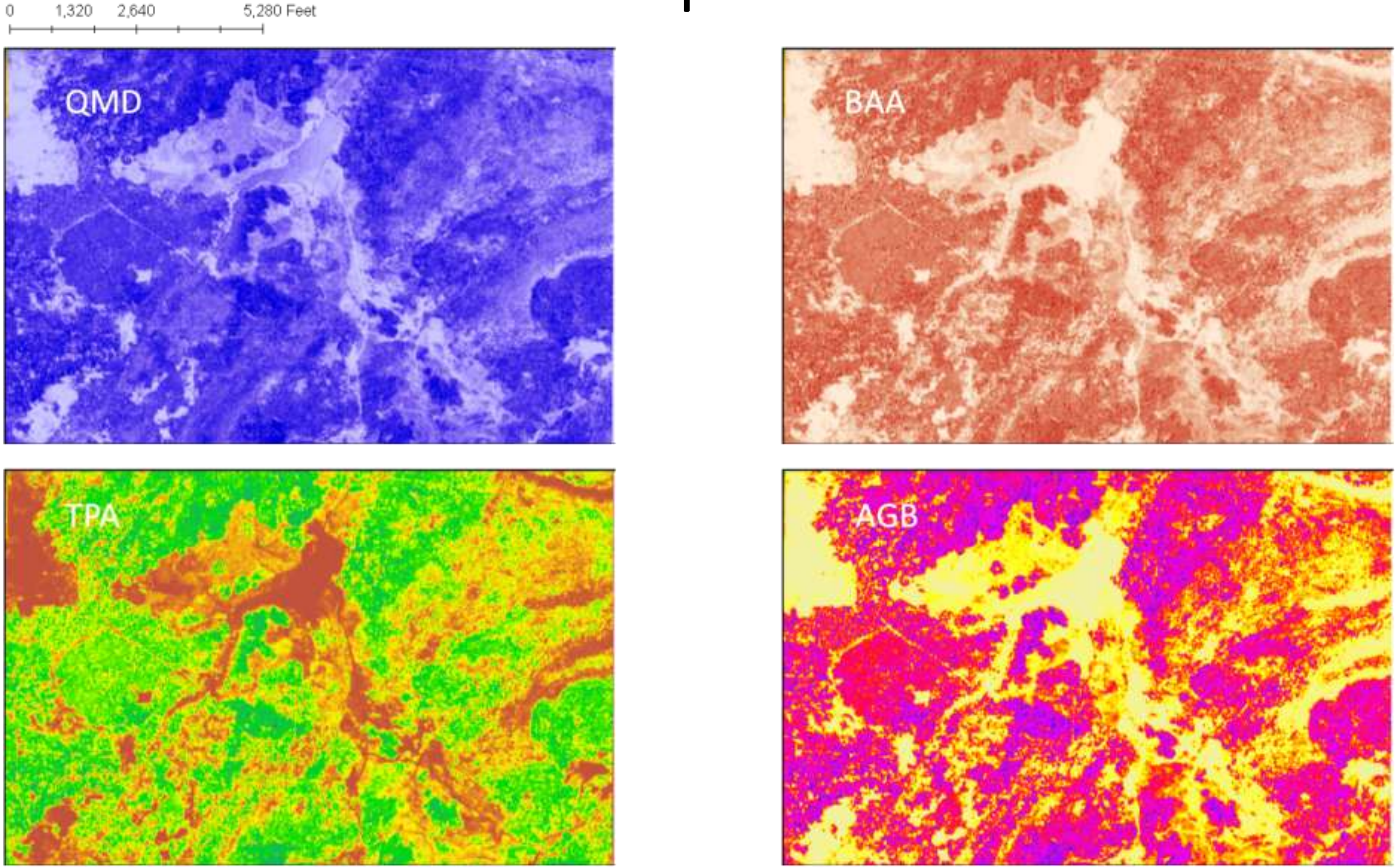
$$AGB_i = \alpha_i + \beta_i \mathrm{X}_j$$

$$QMD_i = \sqrt{\frac{BAA_i}{TPA_i * 0.005454}}$$

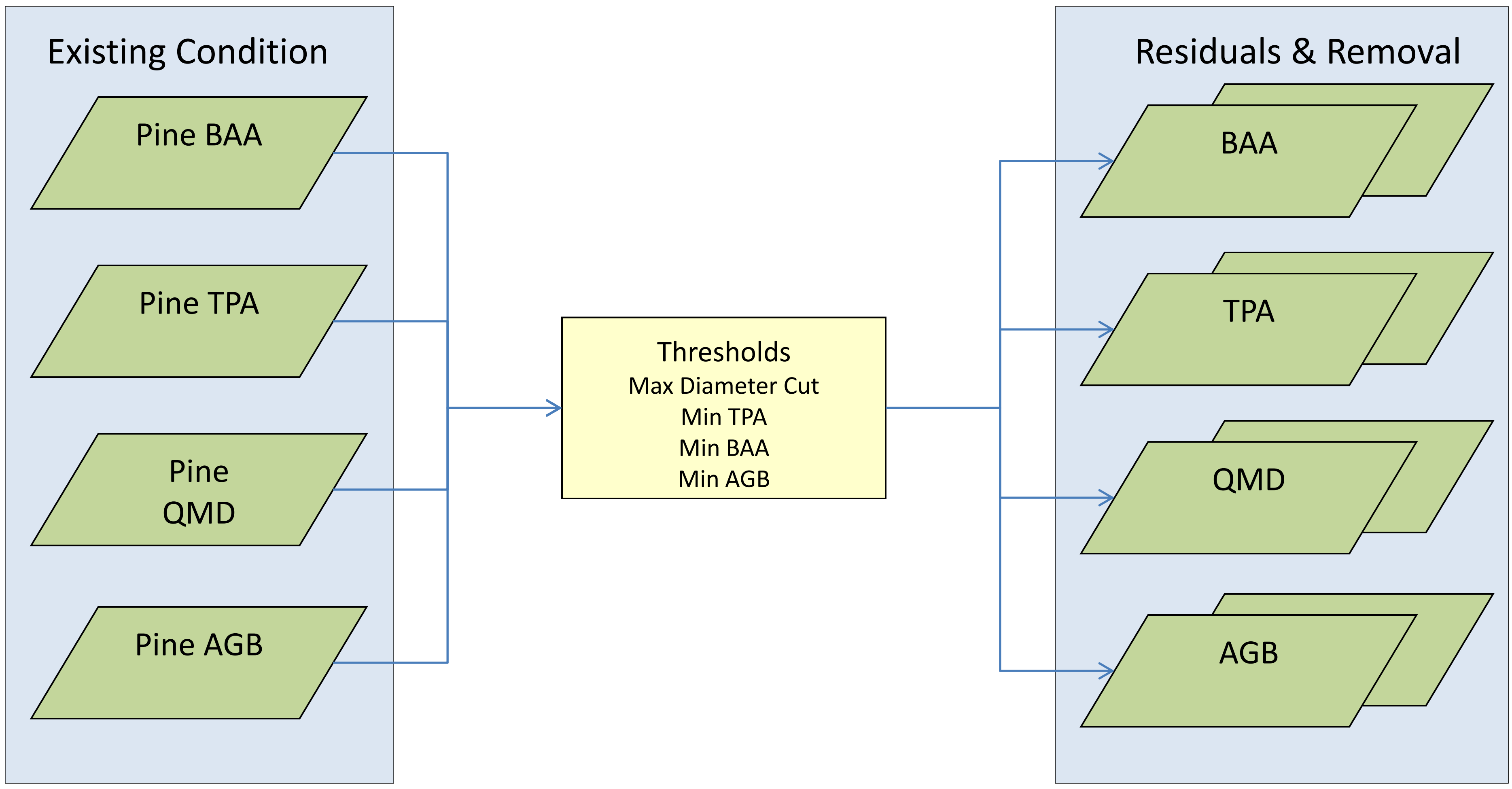
where *i* = 1… number of species groups and *j* = 1… number of predictor variables

Modeled BAA, TPA, and AGB

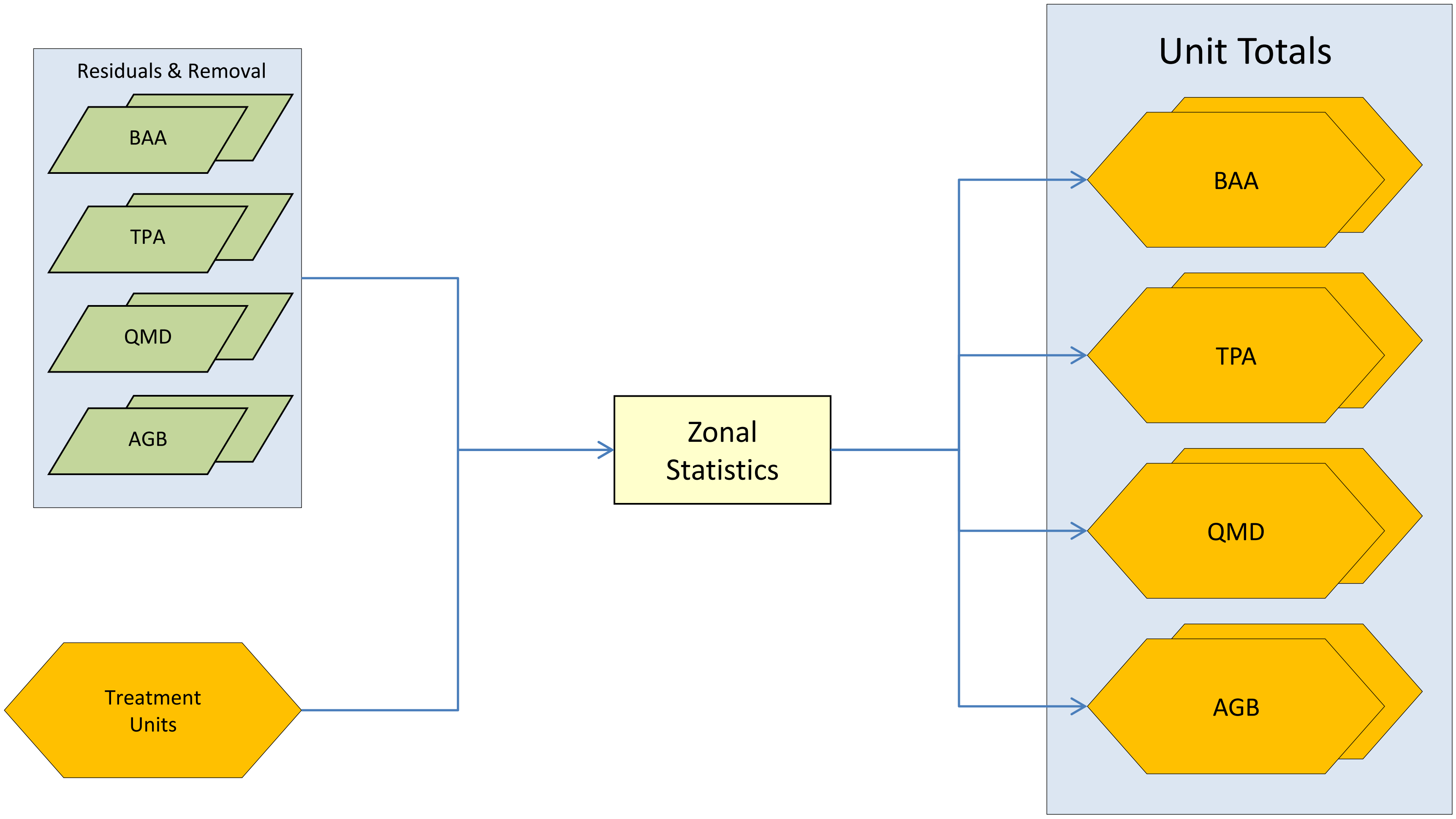
Aspen



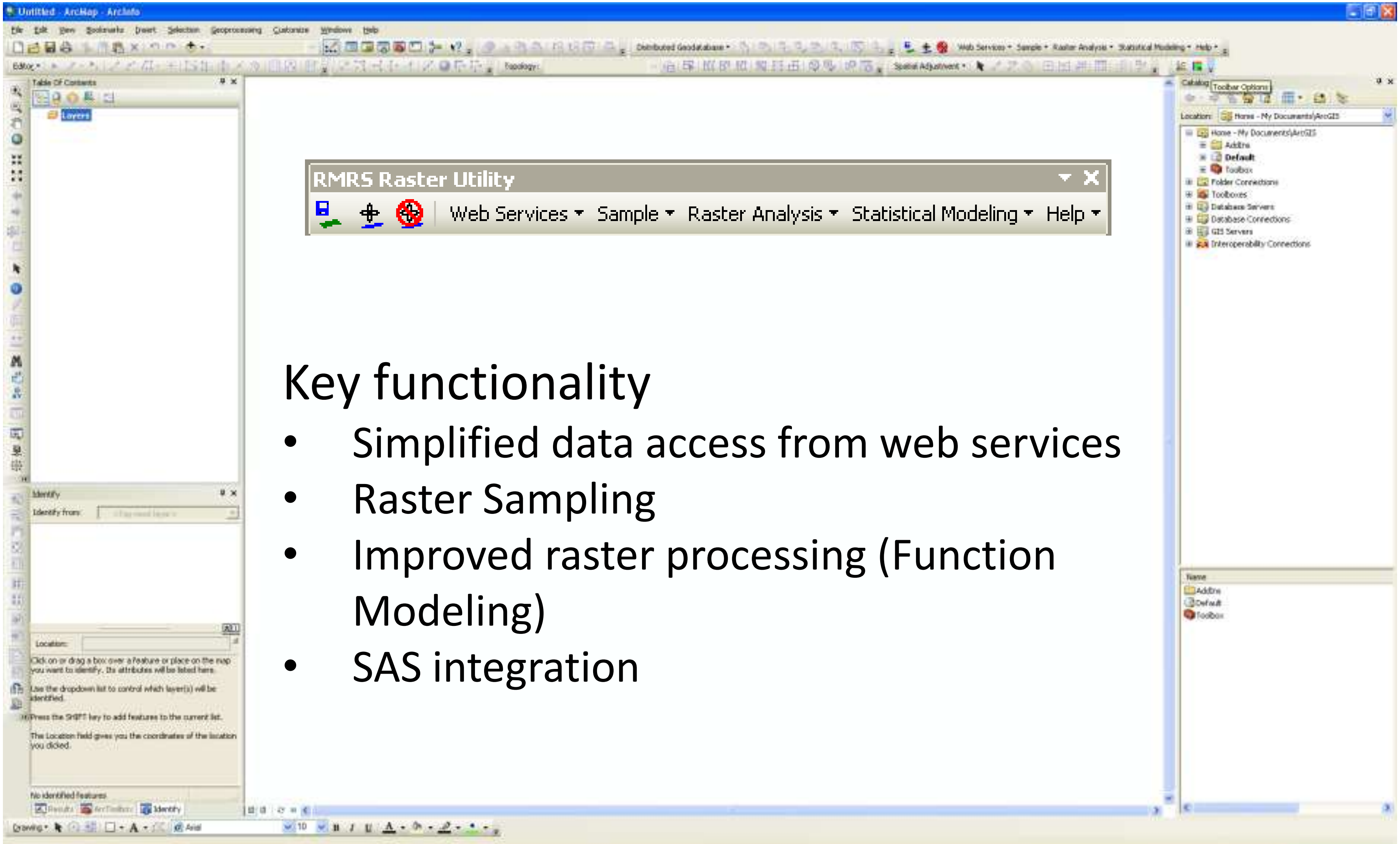
Modeling Management Activity



Summarizing Activities



RMRS Raster Utility Toolbar



Key functionality

- Simplified data access from web services
- Raster Sampling
- Improved raster processing (Function Modeling)
- SAS integration

Contact Information

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