

Wildfire Hazard Assessment

Acadia National Park and surrounding Mount Desert Island, Maine

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Executive Summary

Federal and state fire managers have a critical need for a general baseline geospatial assessment of wildfire risk that identifies areas of particularly high fuel loading. The projected increase in population, pressure for land use change, uncertainties associated with climate change, and declining State and Federal budgets will result in more complex fire suppression strategies. Fire management programs must continue to operate strategically and efficiently to meet this paradigm. The main objectives of this study were to: identify areas in Acadia National Park and the surrounding landscape with high wildfire risk; identify where hazard mitigation practices would be most effective in reducing wildfire risk; to focus resources in the areas of greatest need of fuel reduction. Outside of the 1947 fire boundary, the wildfire risk is generally very high to high with small pockets of moderate to low risk. Within 1947 fire boundary, the wildfire risk is primarily moderate to low with small areas of high to very high risk which is primarily due to topography. The wildfire hazard maps presented are an accurate broad scale representation of the wildfire hazard across Acadia National Park. Due to variances in the reliability of the input data, the scale at which this analysis was conducted, and the range of fuels present throughout the area, conclusions based on the findings of this wildfire risk assessment should be carefully considered at the prescribed fire burn unit scale. Mount Desert Island has and will continue to experience a marked increase in human development and visitation thereby increasing the likelihood of human-caused ignitions. This coupled with the uncertainties of climate change may significantly increase the vulnerability of wildfire occurrence across the Park.

Introduction

To reduce wildfire risk to communities, land managers must identify and prioritize areas for hazardous fuels reduction to minimize damage to natural resources and infrastructure in the event of a wildfire (Hardy 2005; Hessburg et al. 2007; Keane et al. 2010; Thompson et al. 2011; Hmielowski et al. 2016). Spatial data describing fuel loads are critical for strategic decision-making during wildfire events and planning to mitigate wildfire risk across the landscape (Keane et al. 2001; Morgan et al. 2001; Rollins et al. 2004). An approach to mapping wildfire risk that integrates extensive empirical data, remote-sensing technologies, and biophysical modeling is an effective method for identifying priority areas for fuels reduction (Finney 2005; Keane et al. 2001, 2002; Morgan et al. 2001; Rollins et al. 2006; Rollins 2009).

Fuel is the most important single factor influencing fire ignition, spread, and behavior (Pyne et al. 1996). Fuel loading is defined as the amount of fuel present expressed quantitatively in tons per acre. Fuel loading in any given area does not necessarily mean a high-intensity fire will burn. The quality of fuels (e.g., size class, live or dead, wet or dry) available for combustion is more influential in the likelihood of fire than the quantity (Pyne et al. 1996). Fire behavior, thus, is dependent on certain fuel characteristics: type, loading, and availability. Fuel arrangement is also very important in determining wildfire risk and potential fire behavior. There must be horizontal and vertical continuity for a high-intensity fire to burn (Pyne et al. 1996). Since fuel stratum relationships are extremely complex, fire managers often describe fuels by grouping vegetation communities based upon potential fire behavior, into fuel types or fuel models (Anderson 1982; Riano et al. 2002; Scott & Burgan 2005). The fuel type, along with topography and weather, will determine the rate of spread and intensity of fire (Rothermel 1983).

Many wildfire hazard assessments map spatial complexity of fuels indirectly by assigning fuel load characteristics to vegetation types (Miller et al. 2003). This is because remotely sensed data, such as Landsat, do not penetrate the forest canopy thus limiting their utility for mapping surface fuels where tree canopies are present (Keane et al. 2000; Miller et al. 2003). As a result, most wildfire hazard

assessments first classify an image into vegetation categories and then assign fuel types to each category, thus producing a vegetation-type based map (Miller et al. 2003; Falkowski et al. 2005). The greatest challenge in mapping fuels accurately is the high variability of fuels across the landscape even within vegetation types due to disturbance history and succession (Miller et al. 2003; Falkowski et al. 2005). Extensive field data are therefore useful to adequately portray this variability.

The following paper presents methodology for mapping current wildfire hazard at Acadia National Park (ANP) and the surrounding Mount Desert Island (MDI), Maine landscape using an ArcGIS model that extends empirical data of current fuel conditions and spatially portrays wildfire hazard across MDI and beyond. Wildfire risk is evaluated as a function of three primary topics: fuel load (tons/acre), topography, and the wildland-urban interface. The main objective of this study was to identify areas in and nearby ANP with high wildfire risk to focus management resources in the areas of greatest need of fuel reduction. A secondary objective was to evaluate and improve upon available fuel type data (i.e., Scott & Burgan 2005) at the local level. The results of this study can be used to prioritize areas for applying fuel hazard mitigation practices based on anticipated ecological benefits and the estimated management effort and cost required to reduce hazardous fuel loading at ANP.

Methods

Data collection

Vegetation maps interpreted from aerial photos were used to identify 23 homogeneous, approximately 5-to-10 acre (2- to 4-ha) stands, and to establish plots representing the primary forest cover types within ANP (Table 1) (Patterson et al. 1983). Characteristics of sample stands, including fire histories, are described in Patterson et al. (1983). In 2016 variable and fixed radius plots for trees, saplings, shrubs, and fuels were examined in at least 20 plots per stand to characterize the forest composition, structure, and fuel load (Figure 1, 2). The number of transects and plots within each stand depended on the size and shape of the stand. Within each stand, sampling points for standing live and dead, and dead downed woody fuels were located on a grid with points at two-chain intervals along transects running two chains apart. Locations were marked on the 1:50,000 Park USGS map, and GPS waypoint locations were archived with the National Park Service (NPS).

Tree species composition was characterized at each point using a ten factor angle gauge (Cruz-All). Diameters at breast height (dbh) to the nearest 0.1 in. (0.254 cm) were recorded by species for stems ≥ 1 in. (2.54 cm) in diameter. Standing biomass (live and dead fuels) were determined at each sample point in fixed-radius 0.01 acre (0.004 ha) and 0.001 acre (0.0004 ha) plots centered on the point (Figure 2). Trees ≥ 4.5 ft. (1.4 m) tall and < 1 in. (2.54 cm) dbh were tallied by species in 1 ft. (0.3 m) size classes in the 0.01 acre (0.004 ha) radius plots. The number of shrubs, tree seedlings, and advanced regeneration < 4.5 ft. (1.4 m) tall were recorded by 1 ft. (0.3 m) height classes in 0.001 acre (0.0004 ha) radius plots.

To sample downed fuels, a transect was established in a randomly determined direction originating at each point. Along each transect, downed woody fuels were surveyed using the planar-intersect method (Brown 1974). Sampling transects were 50 ft. (15.2 m) long for 1000-hr fuels [>3 in. (7.6 cm) in diameter], 12-ft. (3.7 m) long for 100-hr fuels [1-to-3 in. (2.5-to-7.6 cm) diameter], and 6 ft. (1.8 m) long for 10- and 1-hr fuels [<1 in. (2.5 cm) and 0.25 in. (0.64 cm) in diameter]. Fuel up to 4.5 ft. (1.4 m) in height was counted if it intersected the plane. Duff depth (in.) and fuel height (in.) was measured at 15 ft. (4.57 m) and 30 ft. (9.15 m) along the fuel transect. Fuel height was measured at its maximum height along the length sampled.

Table 1. Stand type, burn date(s) and stand initiation for sample stands in ANP (Patterson et al. 1983).

<u>Stand Type</u>	<u>Burn Date(s)</u>	<u>Initiation Date</u>
spruce/fir		1850
northern hardwood	1901, 1947	1870-1910
northern hardwood	1947	1870-1900
spruce/fir	1864	1840-1890
cedar	1864, 1889	1889
cedar		1840-1900
red oak	1947	1901
pitch pine	1947	1947
birch-aspen	1947	1947
mixed conifer - hardwood	1780, 1820	1820-1825
spruce/fir		1860-1870
spruce/fir		1860-1915
mixed conifer - hardwood		1840-1865/1890-1910
mixed harwood - conifer	fire scars, no date	1840-1910
spruce/fir	fire scars, no date	1780-1845
spruce/fir		1830-1840/1890-1900
mixed harwood - conifer	1880	1830-1880
spruce/fir	1855, 1910	1855-1910
spruce/fir		1820-1860
mixed harwood - conifer	1880	1830-1920
pitch pine	1860, 1885	1885
birch-aspen	1947	1947
old growth spruce	unknown	unknown

Data analysis

Biomass estimates in tons per acre of individual stems for trees, saplings and shrubs were calculated using regression equations and specific gravity coefficients from Young et al. (1980)[(Ln weight = A+B (Ln DBH or Ln Height))] and was converted to stand mass densities by averaging across plots. Specific gravities for most species were obtained from the U.S. Forest Products Laboratory (Brown 1974). Specific gravity estimates for jack pine and pitch pine were found in Whittaker & Woodwell (1968), Alban (1978), and Ledig (1975). Where specific gravity estimates did not exist for a species, respective general hardwood or softwood weights from Tritton & Hornbeck (1982) were used. Calculations of downed fuel loads by approximate timelag class at the plot level followed Brown (1974). Average secants were taken from Brown (1974). The constants d^2 (squared average-quadratic-mean diameters for slash and non-slash ground fuels) and s (average slope correction factor) are presented for each species in Patterson et al. (1983) and Charpentier (unpublished data).

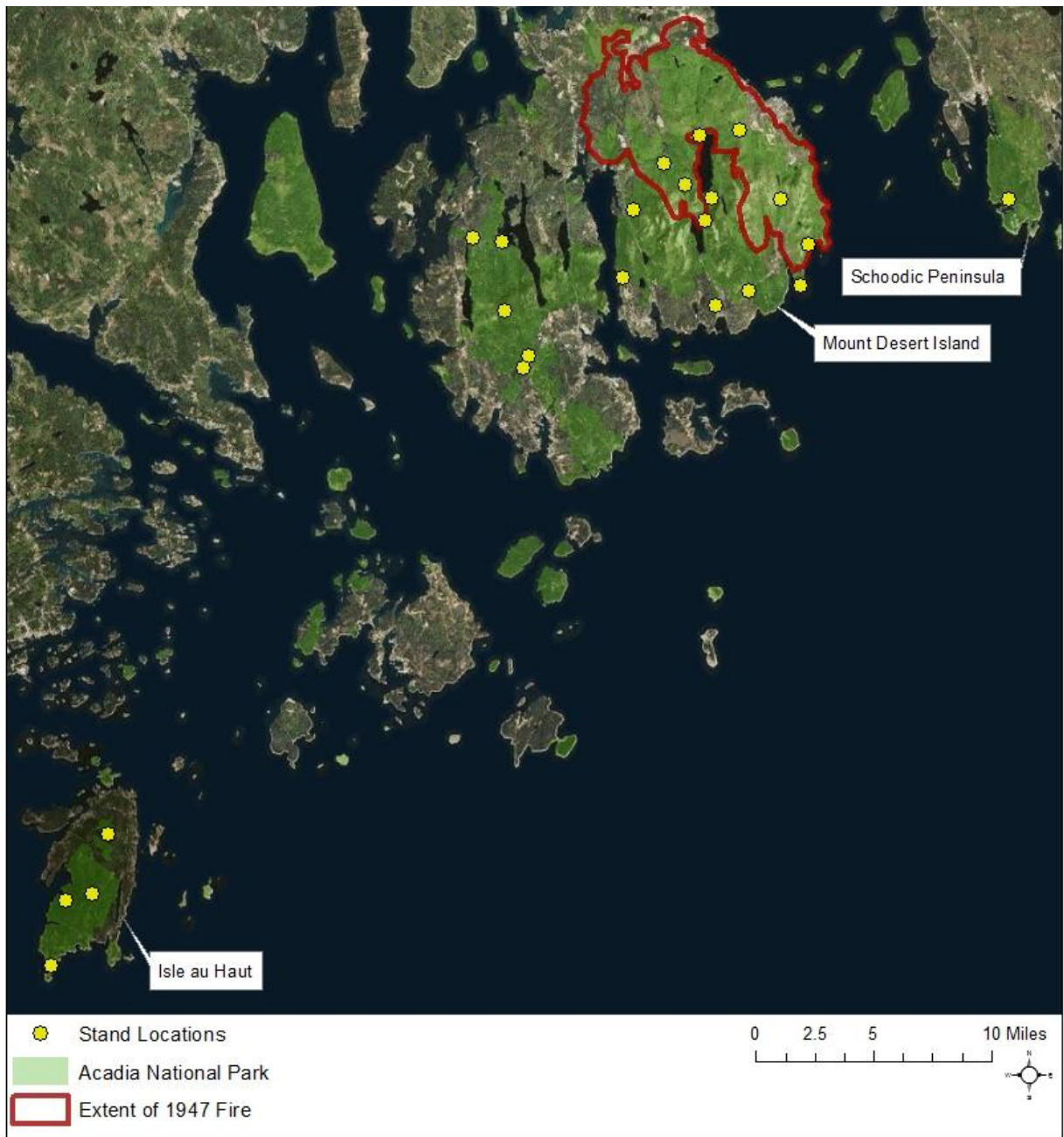


Figure 1. Map showing the stand sample locations for 2016 data collection, the extent of the 1947 fire, and Acadia National Park. GIS coverage of park boundaries and fire extent are courtesy of NPS at ANP.

Plot Layout:

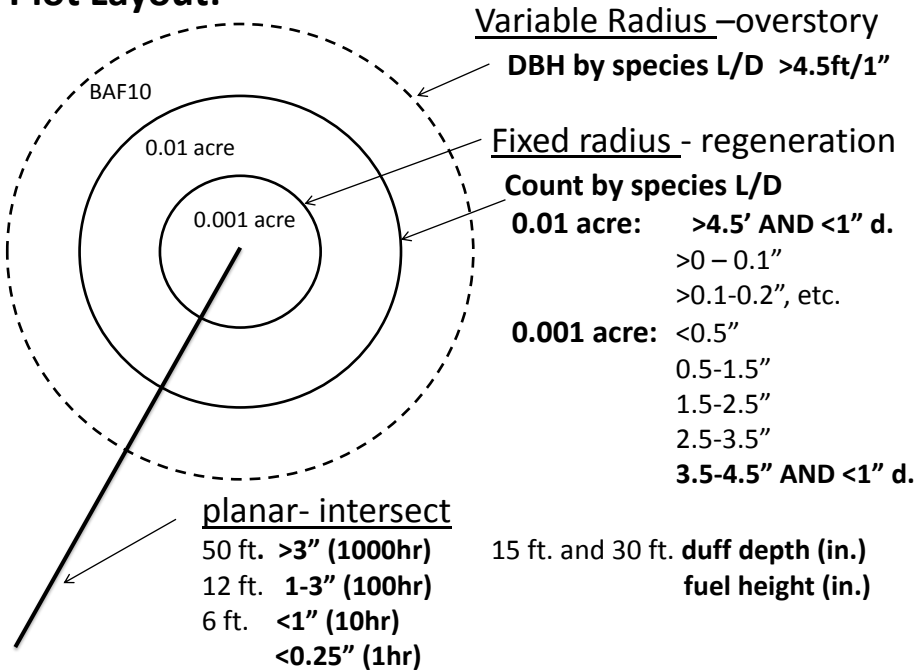


Figure 2. Plot layout for the vegetation and fuels inventory in ANP. L/D = live or dead.

Wildfire hazard model development

The wildfire hazard assessment model followed closely to that of the Northeast Wildfire Risk Assessment (U.S. Forest Service 2010). The purpose was to produce an accurate wildfire hazard map of the ANP landscape and improve upon the Scott and Burgan fuel model (2005) layer used in the regional assessment with ANP plot data. The map is intended to be a general depiction of the wildfire risk for the study area.

The variables in the model included critical factors that affect wildland fire: fuel (i.e., biomass in tons/acre); topography (i.e., slope and aspect) and; the wildland-urban interface (Figure 3). The integration of these variables was applied in a hierarchical scheme. The following percent influence and weights were assigned for each input layer: fuels – 80% influence on the model (very high risk = weight of 5, high risk = 4, moderate risk = 3, low risk = 2, very low risk = 1); topography – 10% influence on the model and; wildland-urban interface – 10% influence on the model. These were combined using a weighted overlay and masking technique to develop the output wildfire hazard assessment.

Tree data were normally distributed. Regeneration, shrubs, ground fuel, and total biomass (tons/acre) were right skewed and thus Log_{10} transformed. Outliers were not removed because they represented areas of particularly high or low biomass accumulation. A combination of plot data, remote sensing, and ESRI ArcGIS software were used to predict fuel loading spatially across ANP. The plot data were reclassified according to GIS spatial data of vegetation community types as defined by, a) vegetation community types at ANP (National Park Service 2003), b) The Nature Conservancy's habitat types (Ferree and Anderson 2013), and c) Scott and Burgan fuel models (2005) (Table 2). The plot data by classified vegetation types were evaluated with the associated raster values from a 2016 Landsat 8 image processed with Normalized Difference Vegetation Index (NDVI $[\text{NIR-R}/\text{NIR+R}]$) methodology, the Woods Hole NACP Aboveground National Biomass and Carbon Baseline Data V.2 estimate of biomass (NBCD) (Kelldorfer et al. 2013), and the regionally refined current biomass grid based on the Woods Hole NACP data produced by the University of Massachusetts' Landscape Ecology Lab

(UMASS)(McGarigal et al. 2017). There were seven independent analysis; six separate linear regressions using the classified plot data and raster values of the three spatial data layers listed above to evaluate the relationship between the field measured biomass and the spatial data as a biomass predictor (Table 2). The seventh analysis was a Classification and Regression Tree (CART) using all data combined to determine the best fit biomass predictor unconstrained by the vegetation type classifications. The Landsat image selected for processing was acquired on August 23, 2016. This image was captured at the same season as the data were collected, and presented good cloud-free coverage for discriminating different vegetation communities. Values from raster images were extracted in ArcMap 10.6 and the data were used as predictors to extrapolate biomass across the landscape. Models were built using the lm function and rpart function in the rpart package (Therneau 2018) with R statistical software (R Core Team 2018).

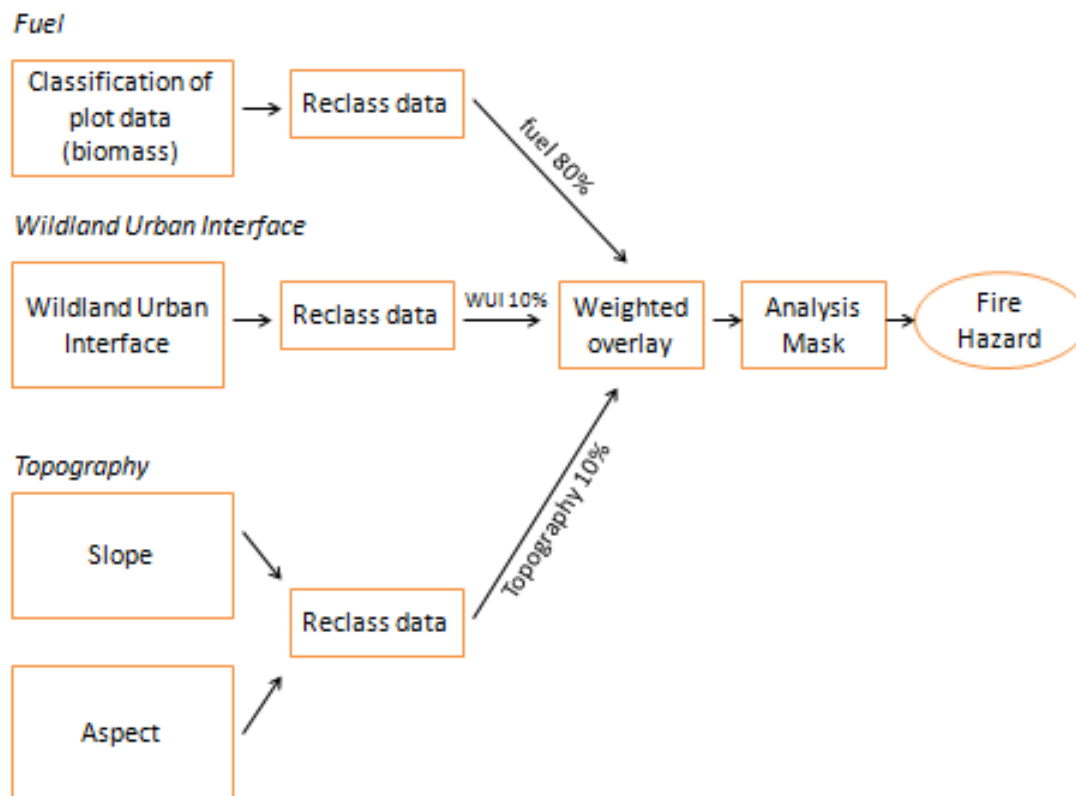


Figure 3. Acadia National Park wildfire hazard risk assessment model (adapted from U.S. Forest Service 2010).

We intended to predict biomass from the plot data on a 30m cell grid level from the best available remotely sensed data, however, due to the initial results described below additional methods were used to extrapolate the spatial arrangement of biomass in the study area. We used vegetation flammability categories, which was a reclassification of the vegetation community types at ANP (National Park Service 2003) to portray biomass in the final wildfire hazard assessment because of the overall accuracy of the NPS vegetation data and its' correlation with successional stage and subsequent relationship to total biomass. Vegetation flammability was defined by how well species burn and was determined by local fire management professionals. Using the flammability categories (Appendix 1), the NPS vegetation data were given weights associated with wildfire risk whereby spruce/fir/cedar were assigned a weight of 5, mixed conifer-deciduous were assigned a weight of 4, red/white/jack/pitch pine

were assigned a weight of 3, birch/aspen/northern hardwood were assigned a weight of 2, and health/grass/shrub were assigned a weight of 1 in the weighted overlay. The wildfire risk scores were compared with the total average biomass by stand as measured in the field as a means of assessing the relationship between the flammability categories and biomass.

Topography has a large impact on fire behavior, of which slope is considered the critical factor. The steeper the slope the faster the fire will burn (Pyne et al. 1996). South and southwest slopes are the most critical in terms of start and spread of wildfires (Chuvieco & Congalton 1989; Pyne et al. 1996). For these reasons, two LANDFIRE data layers were modified and combined in the model: slope and aspect. The slope data layer identified only those pixels that represented a slope greater than 20 percent. The aspect data layer identified only those pixels which represented aspect values between 135 and 315 degrees. The data used in the model thus contained only those pixels that had both a slope greater than 20 percent and an aspect between 135 and 315 degrees (U.S. Forest Service 2010). Developed areas, urban, residential, mixed urban, built-up, roads, and open water as identified by the National Park Service (2003) received a weight of zero and were masked in the model to eliminate non-burnable covers from analysis to produce the final wildfire hazard assessment.

Results

Outside of the 1947 fire boundary, the wildfire risk for MDI is generally very high to high with small pockets of moderate to low risk. Within 1947 fire boundary, the wildfire risk is primarily moderate to low with small areas of high to very high risk which is primarily due to topography (Figure 4). The wildfire hazard for Schoodic Peninsula and Isle au Haut is very high to high with small pockets of moderate to low risk (Figure 5). The input GIS base layers which were used in the weighted overlay and analysis mask are shown in Appendices 1 through 4. In total six linear regression models were compared to determine the best fit biomass predictor. Evaluation of the available regional spatial data showed weak correlations between NDVI, UMASS, NBCD and the reclassified vegetation categories of plot data used in the linear regressions (Table 2). Appendices 5 through 47 show the model outputs of vegetation community categories according to spatial data layer (National Park Service: Appendices 5-30; The Nature Conservancy: Appendices 31-39 and; Scott and Burgan fuel models: Appendices 40-46). All models were weak, but the ANP vegetation flammability categories with the NDVI spatial data had the strongest relationship to total biomass as measured in the field (spruce/fir/cedar: $p=0.02$, $r^2=0.016$; mixed conifer- deciduous: $p=5.67E-08$, $r^2=0.256$; red/white/jack/pitch pine: $p=0.00079$, $r^2=0.45$; birch/aspen/northern hardwood: $p=0.47$, $r^2=0.37$) (Table 2, Appendix 1).

Overall classification accuracy for the CART analysis was 0.62 ($K_{HAT} = 0.327$) (Appendix 47), and is stronger than the species flammability categories alone (accuracy = 0.28, $K_{HAT} = -0.09$). However, because this model was also weak we used the flammability categories as the biomass predictor in the final wildfire hazard assessment because based on results of a thematic accuracy assessment, the estimated overall accuracy for vegetation classes representing ANP community types is 0.80, with a K_{HAT} index of 0.79 (National Park Service 2003). We used vegetation flammability categories as the biomass predictor because of the overall accuracy of the NPS vegetation data and its' correlation with successional stage and subsequent relationship to total biomass.

The wildfire hazard for the entire study area with plot data symbolized by fuel loads (average total tons/acre) as a means of visually assessing the accuracy of the final product is shown in Figure 6. Across all stands sampled, total dead downed woody fuel ranged from 1.32 to 28.04 tons/acre. Standing live trees ranged from 12.9 to 78.1 tons/acre. Standing live regeneration ranged from 0.04 to 0.62 tons/acre. Standing live shrubs ranged from 0.07 to 46.82 tons/acre. Standing dead trees ranged from 0.10 to 17.6 tons/acre. Standing dead regeneration ranged from 0 to 0.16 tons/acre. Standing dead shrubs ranged from 0 to 0.29 tons/acre (Table 3). The values presented in Table 3 are the values

associated with the total fuel loads by stand shown in Figure 6. The average duff depth for all sampled stands ranged from 1.24 to 7.70 inches. Average fuel height ranged from 0.84 to 9.97 inches. Average depth to bedrock ranged from 2.24 to 17.4 inches. Average percent canopy closure ranged from 0.42 to 0.96 percent closure (Table 4). This model met the goal to improve upon the Scott and Burgan fuel model layer (Table 2) which was used in the Northeast Wildfire Risk Assessment (U.S. Forest Service 2010).

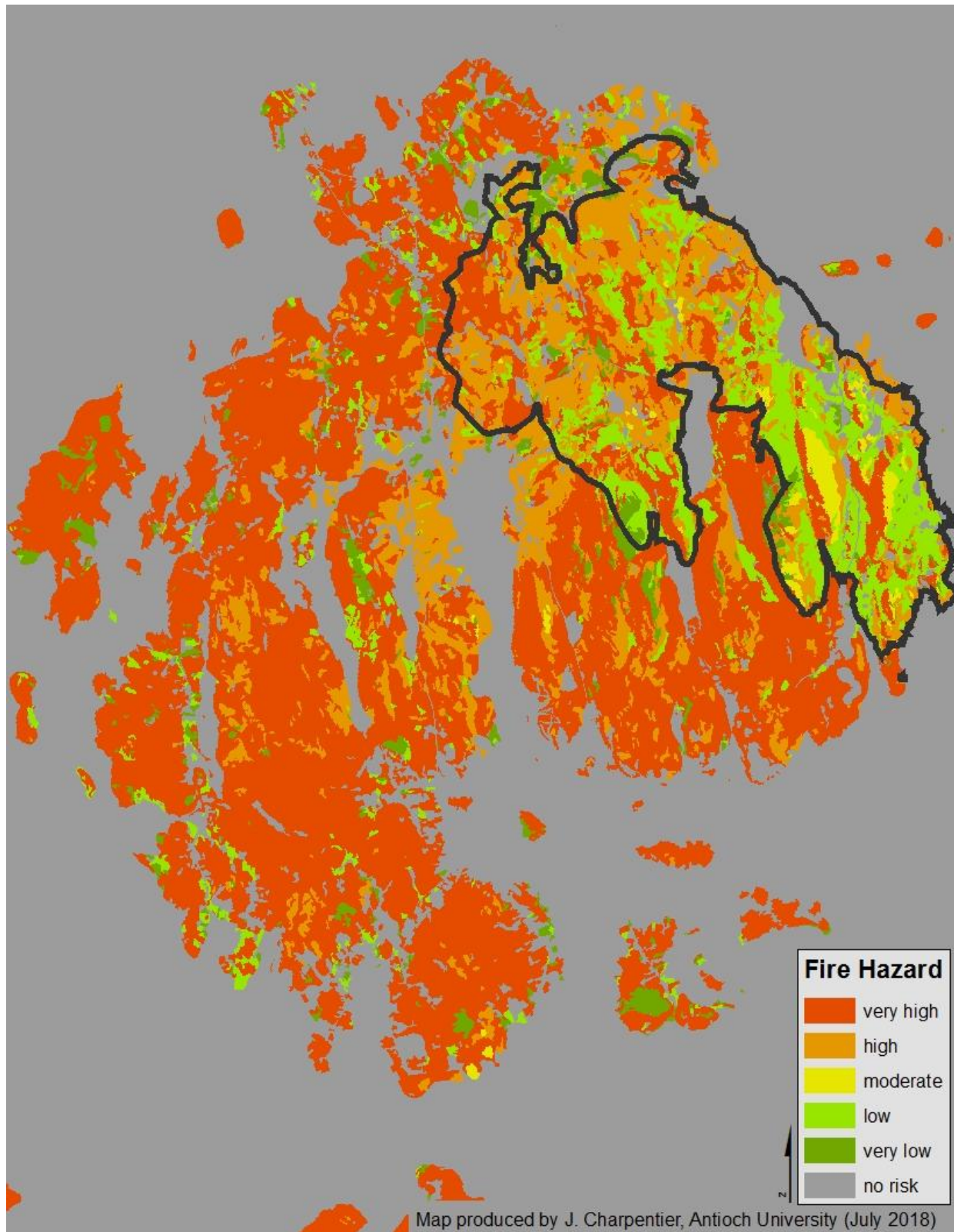


Figure 4. Wildfire hazard for Mount Desert Island, Maine.

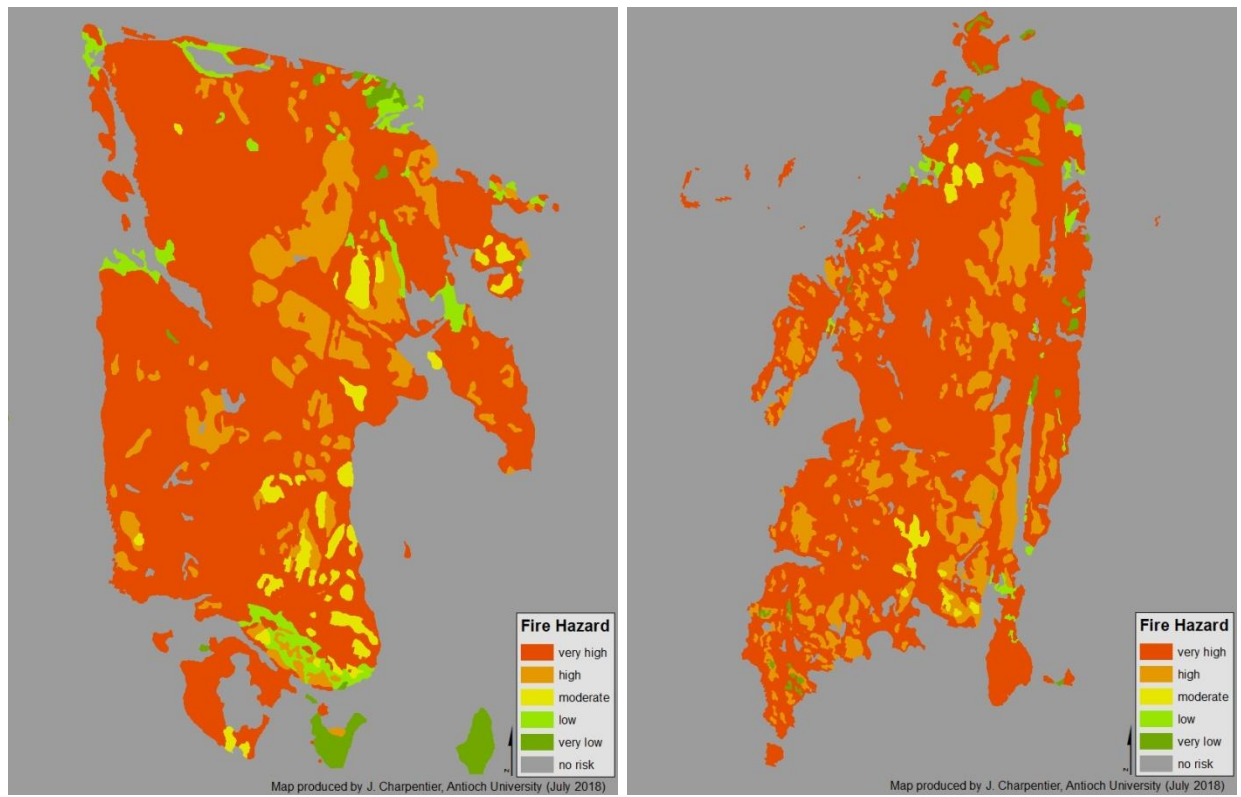


Figure 5. Wildfire hazard for Schoodic Peninsula (left) and Isle au Haut (right), Maine.

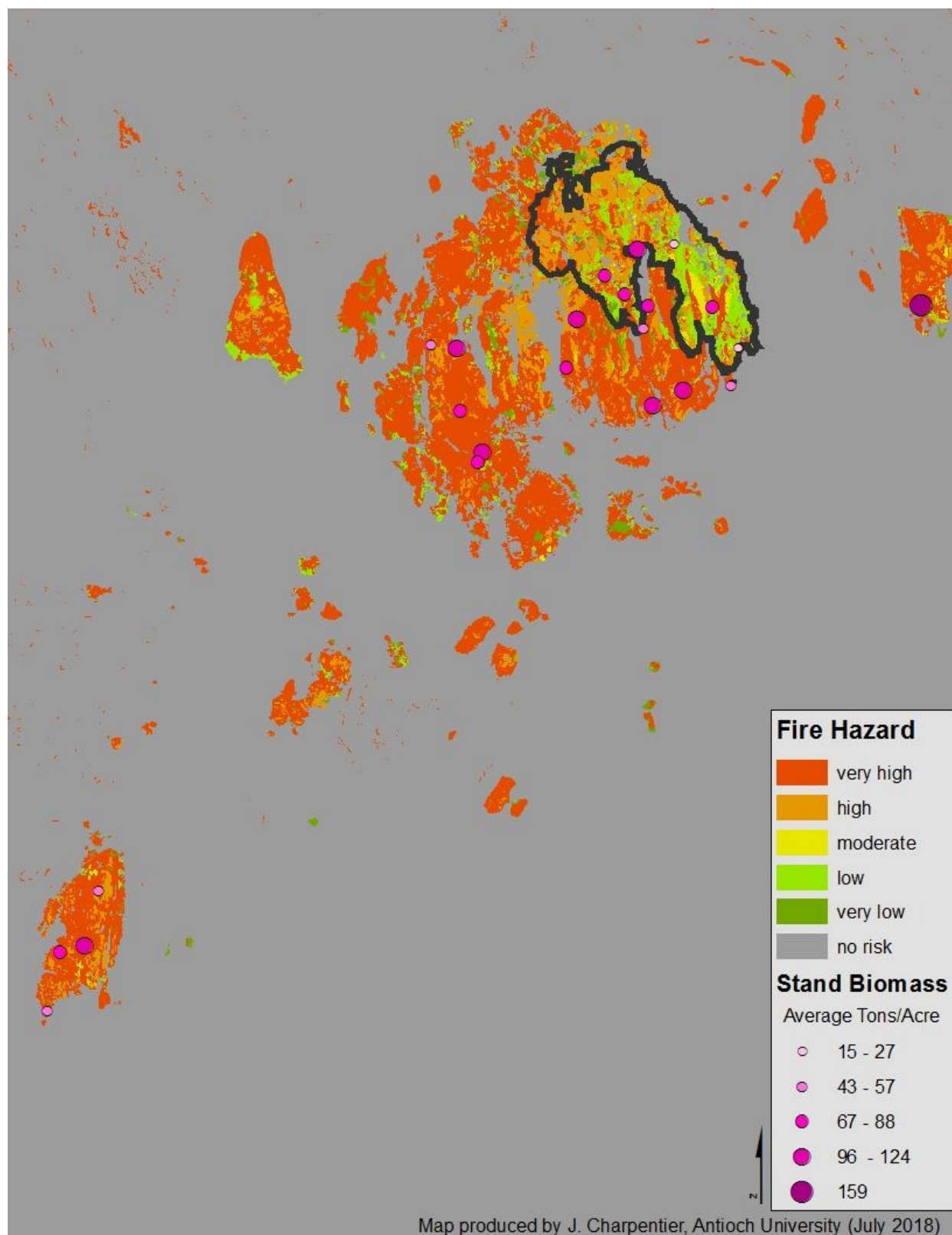


Figure 6. Wildfire hazard for Mount Desert Island, Isle au Haut and Schoodic Peninsula with plot data symbolized by fuel loads (average total tons/acre).

Table 2. Linear regression outputs of plot data classified by community types according to satellite imagery options for biomass mapping.
X indicates sample size too small for statistical inference.

			GIS Spatial Data Layers							
			NDVI		UMASS		NBCD			
			p value=	r ² =	p value=	r ² =	p value=	r ² =		
unclassified plot data (n=471)			0.0003	0.02	0.04	0.008	0.01	0.012		
classified plot data by GIS data community types:			plot count (n)	p value=	r ² =	p value=	r ² =	p value=	r ² =	
<u>National Park Service</u>	conifer	235	0.2136	0.00237	0.9972	-0.00472	0.7951	-0.004		
	mixed	82	9.28E-12	0.2593	0.01948	0.03106	0.03698	0.02192		
	deciduous	154	0.04716	0.03645	0.7202	-0.01224	0.8717	-0.01217		
	conifer	235	0.2136	0.00237	0.9972	-0.00472	0.7951	-0.004		
	mixed (mixed and deciduous combined above)	236	1.34E-12	0.1902	0.001509	0.04141	0.004088	0.03057		
	(A)spruce/fir/cedar	270	0.02019	0.01631	0.8964	-0.00389	0.1565	0.003775		
	(B)mixed conifer-deciduous	99	5.67E-08	0.2556	0.252	0.003827	0.07246	0.02291		
	(C)red/white/jack/pitch pine	20	0.0007884	0.4449	0.4636	-0.02966	0.02501	0.2076		
	(D)birch/aspen/northern hardwoods	82	0.04716	0.03645	0.7202	-0.01224	0.8717	-0.01217		
	(H)high	270	0.02019	0.01631	0.8964	-0.00389	0.1565	0.003775		
<u>The Nature Conservancy</u>	(M)medium	119	6.64E-09	0.2444	0.2125	0.005601	0.1902	0.006198		
	(L)low	82	0.04716	0.03645	0.7202	-0.01224	0.8717	-0.01217		
	spruce/fir/hardwood (community type in layer)	320	0.001604	0.02782	0.9262	-0.00336	0.07156	0.007061		
	conifer	48	0.0007891	0.2023	0.6274	-0.0172	0.2973	0.00236		
	mixed	322	0.001712	0.02728	0.9462	-0.00335	0.2973	0.00236		
	deciduous	101	0.0001427	0.1279	0.1417	0.01393	0.2179	0.005349		
	<u>Scott and Burgan</u>	GS1	3	X	X	X	X	X	X	
		GS3	4	X	X	X	X	X	X	
		NB1	11	X	X	X	X	X	X	
		SH3	19	X	X	X	X	X	X	
TL2		105	0.243	0.00363	0.515	-0.0056	0.0008453	0.09426		
TL3		75	0.5944	-0.0097	0.4697	-0.00708	0.1666	0.0127		
TL5		199	0.04709	0.01489	0.2665	0.001436	0.5481	-0.00323		
TL6		8	X	X	X	X	X	X		
TU1		21	X	X	X	X	X	X		
TU3		26	X	X	X	X	X	X		

Table 3. Fuel loading in 2016 for dead, downed woody material and standing live and dead material (tons/acre).

* indicates stands burned in 1947.

			Downed Woody Fuel										Standing Woody Fuel									
			(tons/acre)										(tons/acre)									
Fuel	Model					Sound	Rotten		Live							Dead						
NFDRS	FBPS	Stand	1-hr	10-hr	100-hr	1000-hr	1000-hr	Total	Trees	STDEV	Regen.	STDEV	Shrubs	STDEV		Trees	STDEV	Regen.	STDEV	Shrubs	STDEV	
H	8	AC01	0.42	0.13	1.97	8.59	2.00	13.11	77.3	25.71	0.12	0.15	0.66	1.78		9.6	8.11	0.02	0.04	0.00	0.00	
R/E	8/9	*AC02	0.35	0.15	1.76	0.78	1.26	4.31	66	20.61	0.06	0.08	0.58	1.28		9.5	7.55	0.03	0.07	0.00	0.00	
R/E	8/9	AC03	0.37	0.11	1.16	3.32	3.03	7.99	73.3	22.92	0.10	0.07	0.08	0.13		6.1	6.79	0.01	0.03	0.00	0.00	
H	8	AC04	0.61	0.14	0.94	2.80	4.01	8.51	78.1	17.02	0.18	0.27	1.50	3.50		7.9	8.67	0.15	0.31	0.00	0.01	
H	8	AC05	0.41	0.10	1.41	2.88	1.79	6.59	43	15.48	0.10	0.12	0.59	2.27		6.7	4.71	0.01	0.03	0.00	0.00	
H	8	AC06	0.36	0.11	1.40	12.26	1.65	15.78	71.9	28.90	0.20	0.18	1.66	2.18		12.8	7.80	0.01	0.03	0.04	0.12	
R/E	8/9	*AC07	0.30	0.12	1.70	0.08	1.38	3.59	61.9	16.38	0.13	0.21	0.13	0.12		5.5	5.04	0.01	0.01	0.00	0.00	
Q	6	*AC08	0.52	0.08	1.17	0.05	2.22	4.05	21.6	13.23	0.04	0.06	0.98	1.11		0.3	0.78	0.03	0.05	0.00	0.00	
R/E	8/9	*AC09	0.28	0.10	1.34	0.98	1.05	3.76	72.6	23.80	0.10	0.17	0.07	0.07		2.8	3.92	0.02	0.05	0.00	0.00	
H	8	AC11	0.75	0.14	1.20	3.56	3.38	9.04	54.1	18.21	0.06	0.09	0.53	0.70		17.6	9.17	0.03	0.06	0.02	0.10	
H	8	AC12	1.21	0.17	1.40	4.24	5.79	12.81	45.7	19.05	0.14	0.21	2.44	5.01		6.1	5.89	0.01	0.04	0.06	0.27	
H	8	AC13	1.90	0.43	7.67	12.21	5.82	28.04	18.4	17.97	0.35	0.42	0.88	1.74		8.3	8.55	0.01	0.02	0.02	0.07	
H	8	AC15	0.74	0.16	2.27	4.30	4.82	12.29	65	24.28	0.12	0.20	33.94	90.32		13	10.72	0.00	0.01	0.00	0.00	
R/E	8/9	AC16	0.65	0.16	1.58	4.20	4.95	11.55	73	22.44	0.13	0.12	0.75	0.80		16.1	9.78	0.01	0.03	0.03	0.09	
H	8	AC17	0.85	0.12	1.61	9.34	8.01	19.92	76	20.77	0.48	0.60	46.82	139.34		15.4	11.46	0.07	0.13	0.03	0.06	
H	8	AC18	0.83	0.16	1.70	8.19	2.03	12.91	59.86	19.51	0.32	0.41	36.71	75.30		7.66	5.85	0.03	0.07	0.00	0.02	
R/E	8/9	AC19	0.69	0.10	1.30	3.80	1.40	7.30	65.71	17.80	0.36	0.64	4.41	6.16		9.50	9.21	0.08	0.15	0.00	0.01	
Q	6	AC20	0.67	0.09	0.18	1.41	0.06	2.41	38.6	12.15	0.10	0.16	0.64	0.64		4.8	6.59	0.00	0.00	0.00	0.00	
G	10	AC22	1.13	0.17	1.77	1.66	3.96	8.68	35.6	24.24	0.25	0.48	0.61	0.65		3.6	4.92	0.16	0.27	0.22	0.93	
R/E	8/9	AC23	0.55	0.12	2.26	3.70	5.82	12.45	73.8	16.74	0.10	0.11	0.31	0.70		12.5	10.21	0.01	0.03	0.00	0.00	
Q	6	AC24	0.53	0.13	0.61	0.05	0.00	1.32	35.7	13.02	0.05	0.05	3.78	2.42		1.8	2.02	0.00	0.00	0.00	0.00	
R/E	8/9	*AC25	0.23	0.06	0.94	0.05	0.25	1.53	12.9	9.97	0.06	0.14	0.47	0.53		0.1	0.66	0.01	0.02	0.00	0.00	
G	10	AC26	1.01	0.17	2.68	5.63	4.43	13.92	48.6	24.21	0.62	0.68	1.49	1.74		16.5	9.82	0.01	0.02	0.29	1.08	

Table 4. Average duff depth, fuel height, depth to bedrock, and percent canopy closure for stands sampled in 2016. * indicates stands burned in 1947.

Stand	Average		Average		Average		Average	
	Duff Depth (in.)	STDEV	Fuel Height (in.)	STDEV	Depth to Bedrock (in.)	STDEV	Canopy Density (%)	STDEV
AC01	2.51	1.99	3.68	7.11	9.20	3.25	0.92	0.14
*AC02	3.39	1.70	1.49	1.07	17.40	5.30	0.93	0.02
AC03	2.19	1.41	1.48	1.47	12.15	5.34	0.96	0.01
AC04	4.52	1.55	1.10	0.94	10.07	3.09	0.88	0.04
AC05	1.24	1.31	2.21	3.22	2.24	2.41	0.87	0.10
AC06	3.66	1.63	5.94	10.52	11.01	3.82	0.84	0.13
*AC07	3.05	1.03	1.11	0.76	7.91	3.31	0.86	0.05
*AC08	3.61	1.48	0.84	0.81	5.44	2.81	0.42	0.33
*AC09	1.97	0.99	1.66	3.61	11.06	3.70	0.92	0.04
AC11	4.95	2.15	2.54	2.26	8.69	3.64	0.83	0.09
AC12	7.70	2.44	4.31	7.46	8.64	2.67	0.74	0.16
AC13	4.37	2.87	9.97	10.40	8.07	3.39	0.53	0.30
AC15	5.92	2.49	5.18	6.81	7.36	3.43	0.81	0.09
AC16	4.88	1.04	1.04	1.04	8.76	2.93	0.92	0.04
AC17	7.32	4.07	1.70	3.29	10.01	5.98	0.82	0.10
AC18	6.59	1.72	3.57	3.50	10.23	3.60	0.85	0.08
AC19	5.48	1.91	2.51	3.89	12.57	4.56	0.89	0.04
AC20	4.42	2.04	4.18	7.15	8.66	3.88	0.74	0.19
AC22	4.59	2.45	2.84	4.57	6.66	3.30	0.67	0.30
AC23	2.46	1.51	4.62	5.13	12.73	6.63	0.88	0.06
AC24	5.06	2.34	2.84	2.46	5.39	2.23	0.60	0.19
*AC25	3.49	2.34	1.15	1.29	5.23	3.47	0.42	0.35
AC26	5.32	2.04	2.89	5.49	10.84	3.26	0.81	0.16

Discussion

The purpose of this research was to identify areas in and nearby ANP with high wildfire risk to focus management resources in the areas of greatest need of fuel reduction. The methodology was moderately successful in mapping the delineation of fuel loads across the study area. The greatest limitation is that the best available remotely sensed data do not penetrate the canopy of the forest and so only measure above-ground live biomass. Assessment of surface fuels under tree canopies with remotely sensed data has proven in the past to be difficult (Miller et al. 2003). Our intent was to map the total biomass accounting for vertical structure of both live and dead fuels. Given the limitations of available remotely sensed data, we used existing vegetation type data as a surrogate for fuel loads. However, vegetation type alone is not an optimized proxy for fuel loading. The distribution and accumulation of fuels is highly variable (Brown & Bevins 1986) and dependent upon the combined vegetation type, disturbance regime or stand history, structural stage classes, soils, and/or moisture availability (Keane et al. 2000, 2001; Brandis & Jacobson 2003; Miller et al. 2003). Variability of fuels within vegetation type can be greater than variation between types (Miller et al. 2003). Further, if the vegetation type is misclassified in the underlying data, then it will carry through to the final product.

Active remote sensing platforms such as light detection and ranging (lidar) have been used to predict fuel loads, and in general have achieved stronger relationships (Falkowski et al. 2005). Higher accuracies using lidar data are to be expected given their higher information content. A significant amount of the lidar energy can penetrate the forest canopy just like sunlight. Thus, lidar systems can

record information starting from the top of the canopy through the canopy all the way to the ground. This makes lidar highly valuable for understanding vertical structure of the forest. Future fuels mapping efforts at ANP may be more successful by integrating multispectral satellite data with hyperspectral data, lidar data, or both. However availability of low-cost satellite hyperspectral and lidar datasets is limited, and the costs of acquiring and analyzing such data is impractical for most land managers (Falkowski et al. 2005).

Further, it is recognized that the incidence of wildfire due to human-caused ignition while recreating is a missing component in this mapping effort. Often the occurrence and location of wildfire at ANP reflects the activities of humans who cause fires and potentially increase the wildfire risk factor. Inclusion of historical fire occurrence data would enhance the human- ignition potential in the model. Although, human behavior cannot accurately be modeled; fires resulting from malicious intentions or accidents can occur throughout the region when conditions are suitable. Education and preventative measures can mitigate some threat to personal property regardless of the risk or hazard levels.

Due to variances in the reliability of the input data, the scale at which this analysis was conducted, and the range of fuels present throughout the area, conclusions based on the findings of this wildfire risk assessment should be carefully considered at the prescribed fire burn unit scale. However, there is general consensus by ANP land managers who are familiar with local variation that this map generally depicts the wildfire risk at ANP. Although hazard and risk mapping can provide insight into the potential long-term distribution of wildfires, managers and property owners need to continually assess local site conditions as small changes are beyond the scope of this study.

Conclusion

Wildfires pose a serious threat to property and resources, and managers are faced with important management decisions about how to best allocate the limited resources available. Wildfire hazard mapping provides supplemental information on which to base the limited resource allocations. This study aims to provide a tool to spatially project the risk of wildfires across ANP and surrounding landscape. The projected increase in population, pressure for land use change, and declining State and Federal budgets will result in more complex fire suppression strategies. MDI has and will continue to experience a marked increase in human development and visitation in areas surrounding ANP thereby increasing the likelihood of human-caused ignitions. This coupled with the uncertainties of climate change may significantly increase the vulnerability of wildfire occurrence at ANP. The fire management program at ANP must continue to operate strategically and efficiently to meet this paradigm.

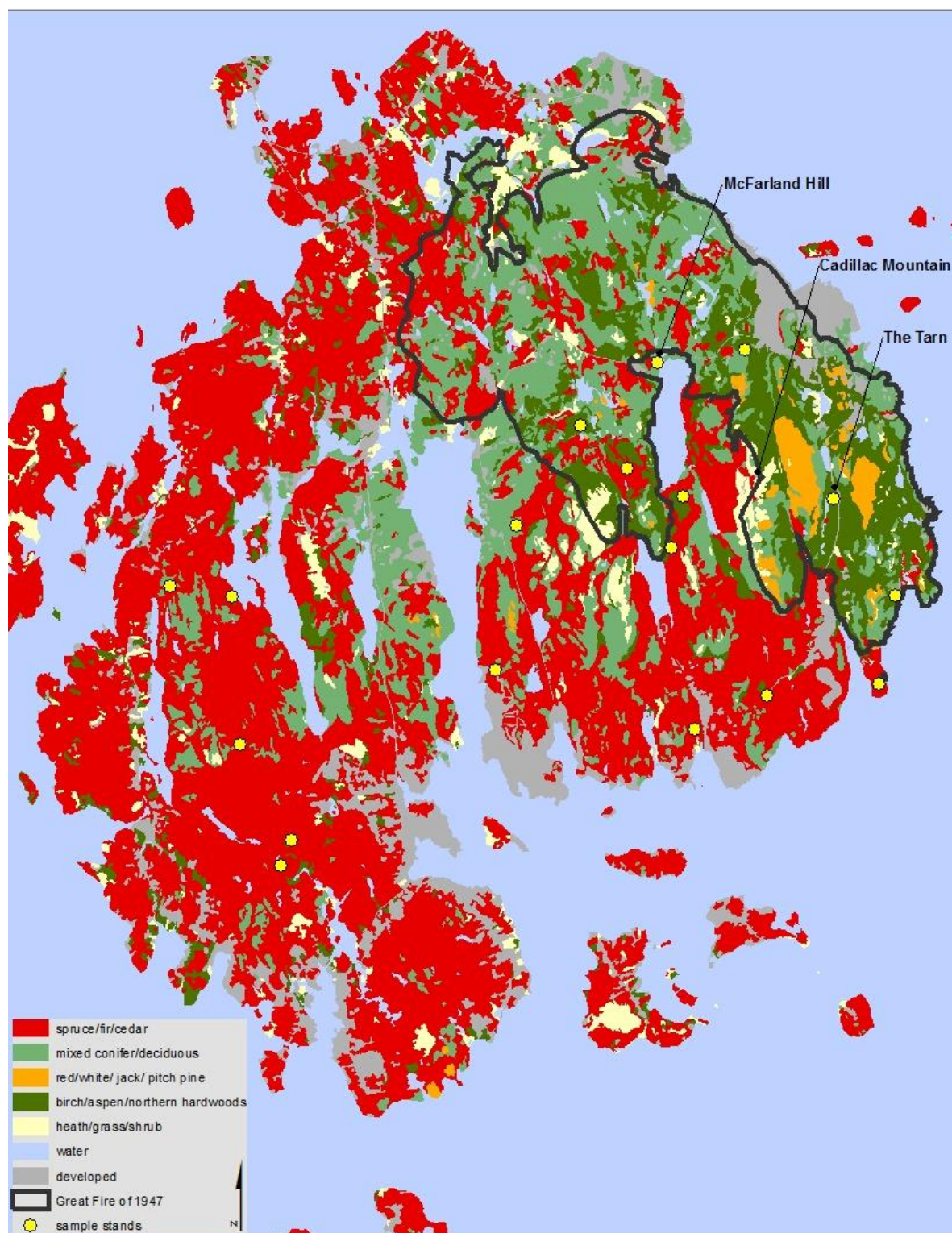
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Appendix 1. Vegetation flamability of Mount Desert Island. Source: Spatial Vegetation Data for Acadia National Park Vegetation Mapping Project, U.S. Geological Survey, Center for Biological Informatics. 2003. Vegetation Information for the Acadia National Park Vegetation Inventory Project.

To express vegetation flammability, cover types were grouped as follows:
(NOT by order of significance)

A. Spruce/fir/cedar (60-100% canopy closure)

Spruce-fir forest (conifer phase)
Spruce-fir forest (mixed phase)
White cedar woodland
Conifer swamp woodland (white cedar stage)
Conifer swamp woodland (spruce-mix phase)
Evergreen plantation

B. Mixed conifer-deciduous (25-60% canopy closure)

Mixed conifer woodland
Mixed conifer-deciduous woodland
White pine –hardwood forest
White pine-mixed conifer forest
Oak-pine forest

C. Red, white, jack, pitch pine:

Pitch pine heath barren
Red pine-white pine forest
Pitch pine-corema woodland
Pitch pine woodland
Jack pine woodland

D. Birch-aspen/northern hardwoods:

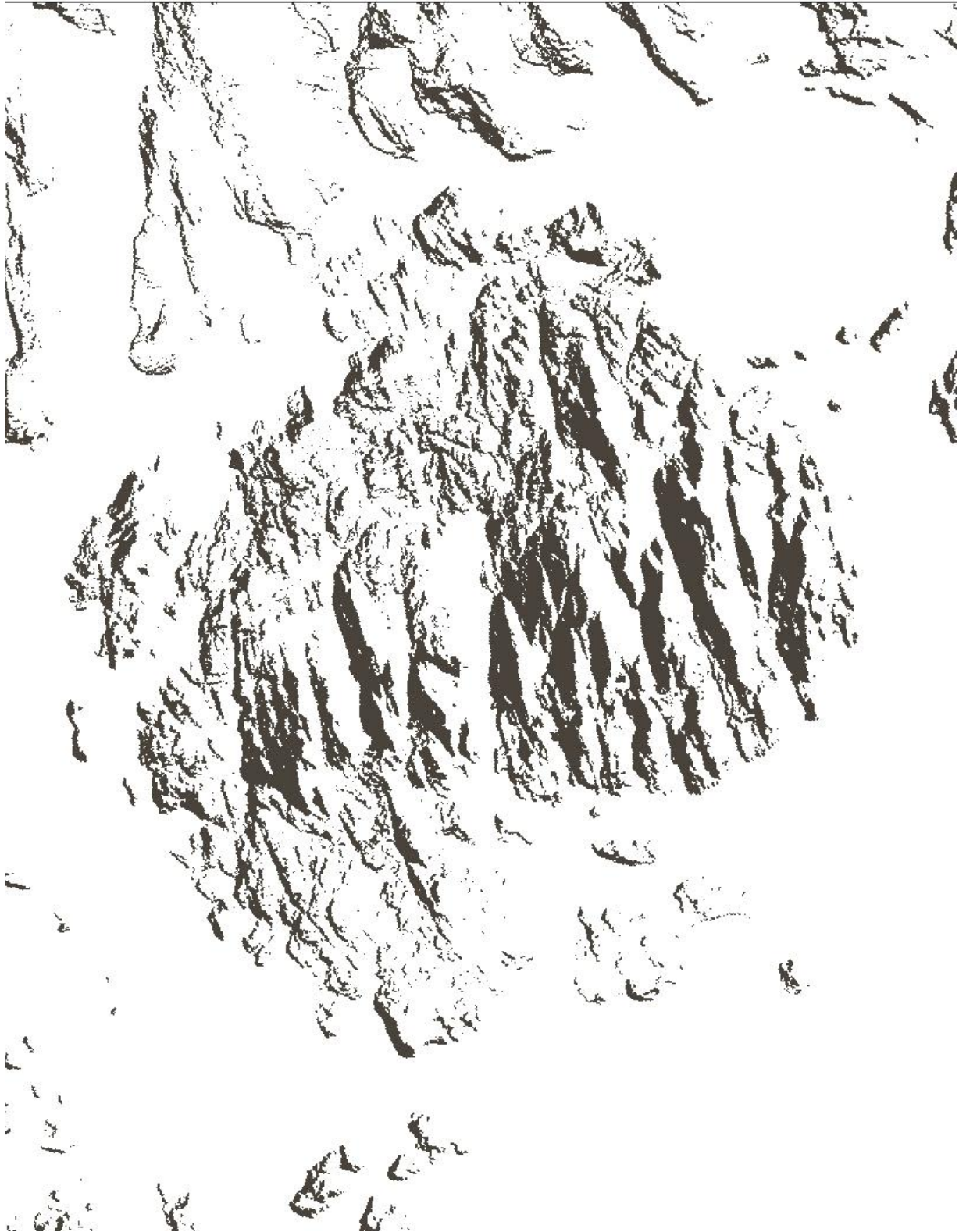
Aspen-birch woodland/forest complex (woodland phase)
Aspen-birch woodland/forest complex (forest phase)
Aspen-birch woodland/forest complex (shrubland phase)
Beech-birch-maple forest
Red oak woodland
Mixed deciduous shrubland
Red maple-hardwood swamp

E. Health, grass, shrub

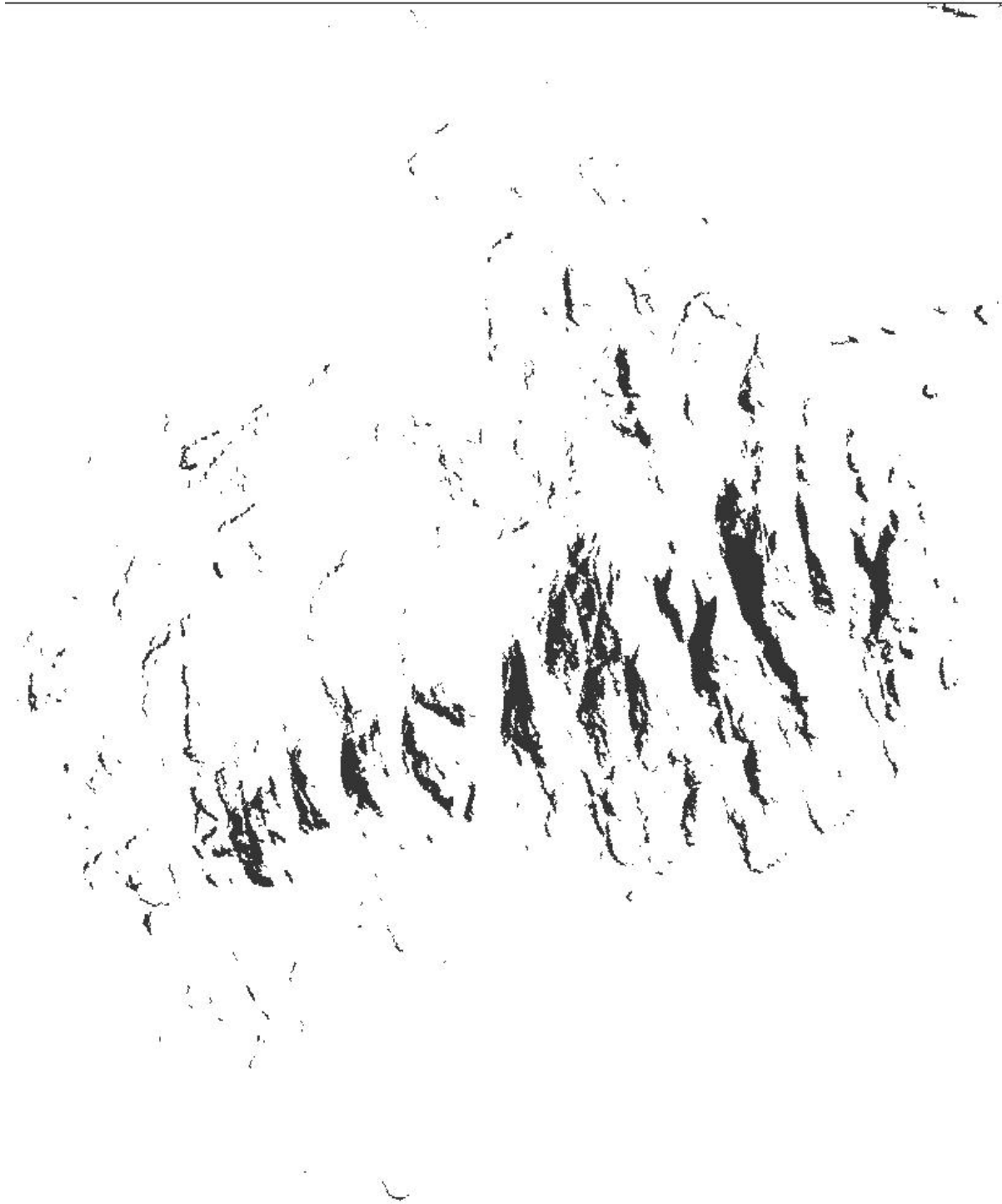
Alder shrubland
Perennial grass crops
Perennial grass crops with sparse shrubs
Mixed-grass forb
Fen Complex
Crowberry-bayberry headland
Dune grassland
Sweetgale mixed shrub fen
Sparsely vegetated talus
Dwarf shrub bog
Blueberry bald-summit shrubland complex
Other agricultural land



Appendix 2. LANDFIRE slope data reclassified to only identify those pixels that represent a slope greater than 20 percent.



Appendix 3. LANDFIRE aspect data reclassified to only include between 135 and 315 degrees. Within this range, solar heating of fuels is expected to contribute to an increase in wildfire risk.



Appendix 4. Topography map which combines LANDFIRE slope and aspect data. The topography map contains only those pixels which are greater than 20% slope and an aspect between 135 and 315 degrees.

Appendix 5. NPS vegetation types by communities as identified in the field. Highlighted grey shows incorrect classifications in NPS GIS data layer.

Count of Community Type	Column Labels									
Row Labels	birch-aspen	cedar	mixed conifer - hardwood	mixed hardwood - conifer	northern hardwood	old growth spruce	pitch pine	red oak	spruce/fir	Grand Total
Aspen-Birch (ABF)	11									11
Mixed Conifer (MCW)						1	17		23	41
Beech-Birch-Maple (MDF)	8			6	36					50
Mixed Conifer-Deciduous (MW)	19									19
Pitch Pine (PPW)	1						19			20
Red Oak (ROW)	1							20		21
Spruce-Fir Forest [conifer phase](SF)			34	2	1	19	4		116	176
Spruce-Fir Forest [mixed phase] (SFM)			5	32	3				34	74
White Cedar Woodland (WCW)		20								20
White Pine - Mixed Conifer (WPC)			1						18	19
White Pine - Hardwood (WPM)		20								20
Grand Total	40	40	40	40	40	20	40	20	191	471

Appendix 6. Reclassification of NPS community types into 3 categories: conifer, mixed, deciduous ('green'). Highlighted grey shows incorrect classifications in NPS reclassification GIS data layer.

Count of NPS_reclass	Column Labels									
Row Labels	birch-aspen	cedar	mixed conifer - hardwood	mixed hardwood - conifer	northern hardwood	old growth spruce	pitch pine	red oak	spruce/fir	Grand Total
conifer	1	20	35	2	1	19	23		134	235
green	20			6	36			20		82
mixed	19	20	5	32	3	1	17		57	154
Grand Total	40	40	40	40	40	20	40	20	191	471

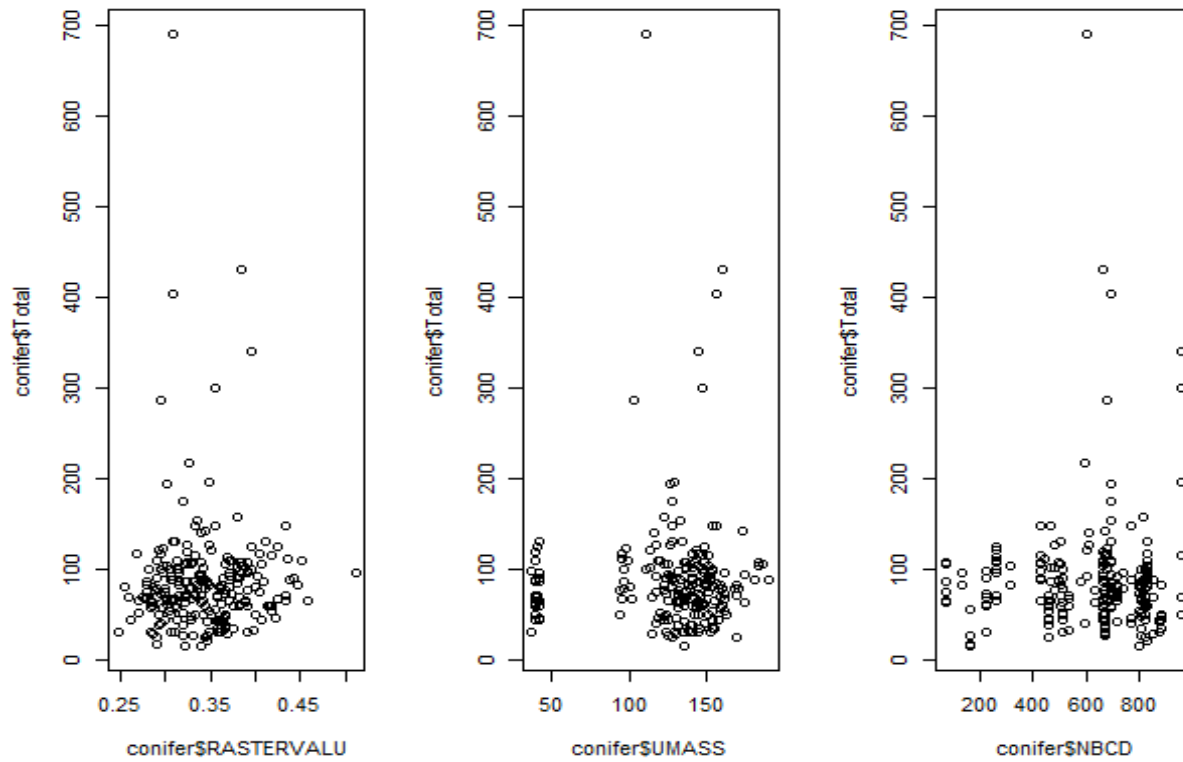
Conifer: WPC, SF, PPW, WCW

Green: ABF, MDF, ROW

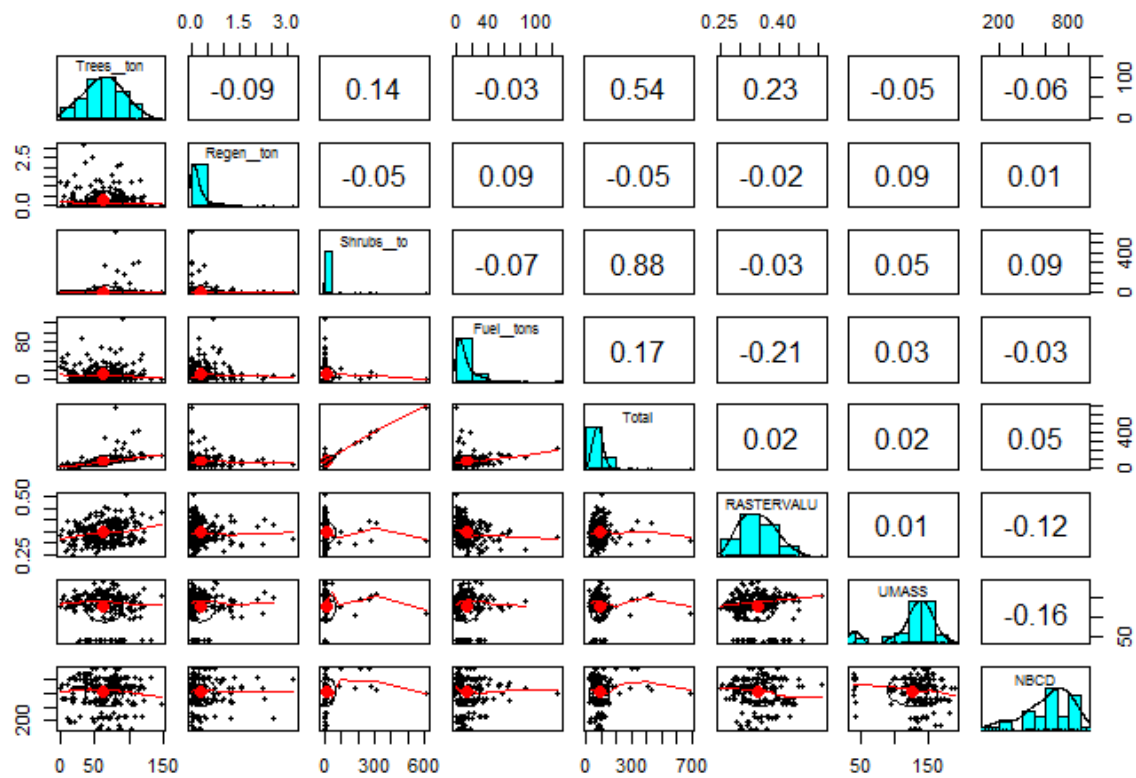
Mixed: SFM, MCW, MW, WPM

*see Appendix 5 for code explanations

Conifer:

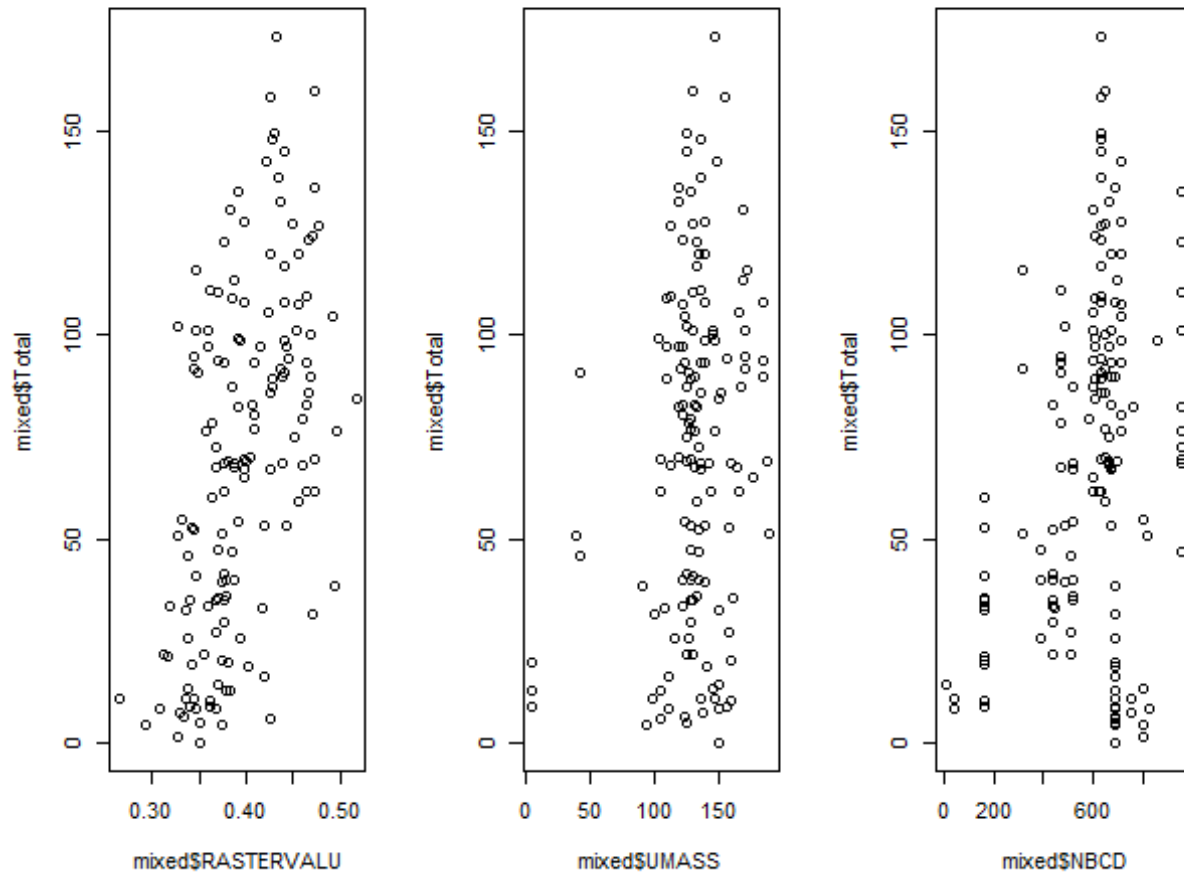


Appendix 7. NPS vegetation reclassification -total conifer biomass (tons/acre) by NDVI, UMass, and NBCD raster values.

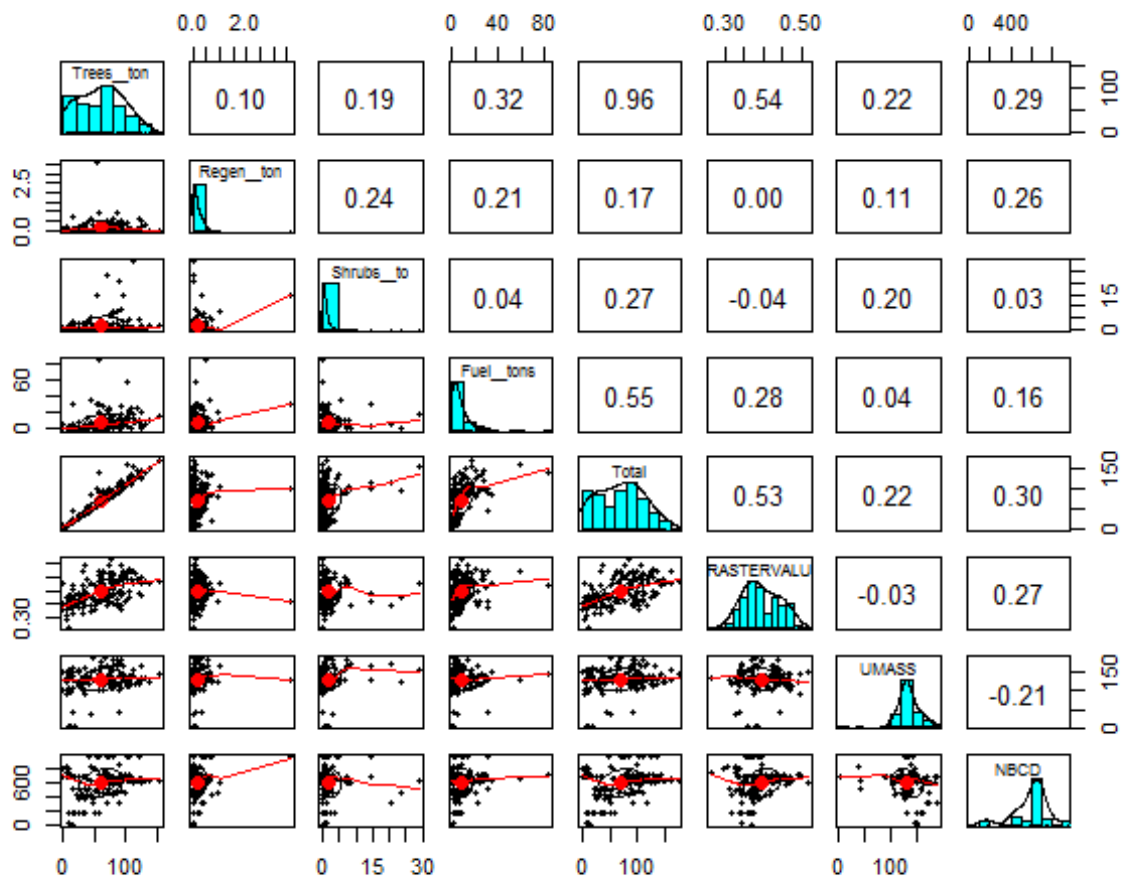


Appendix 8. NPS vegetation reclassification – Vertical structure of conifer biomass (tons/acre) by satellite imagery options (NDVI of Landsat 8 image, UMASS Biomass, and National Biomass and Carbon Dataset).

Mixed:

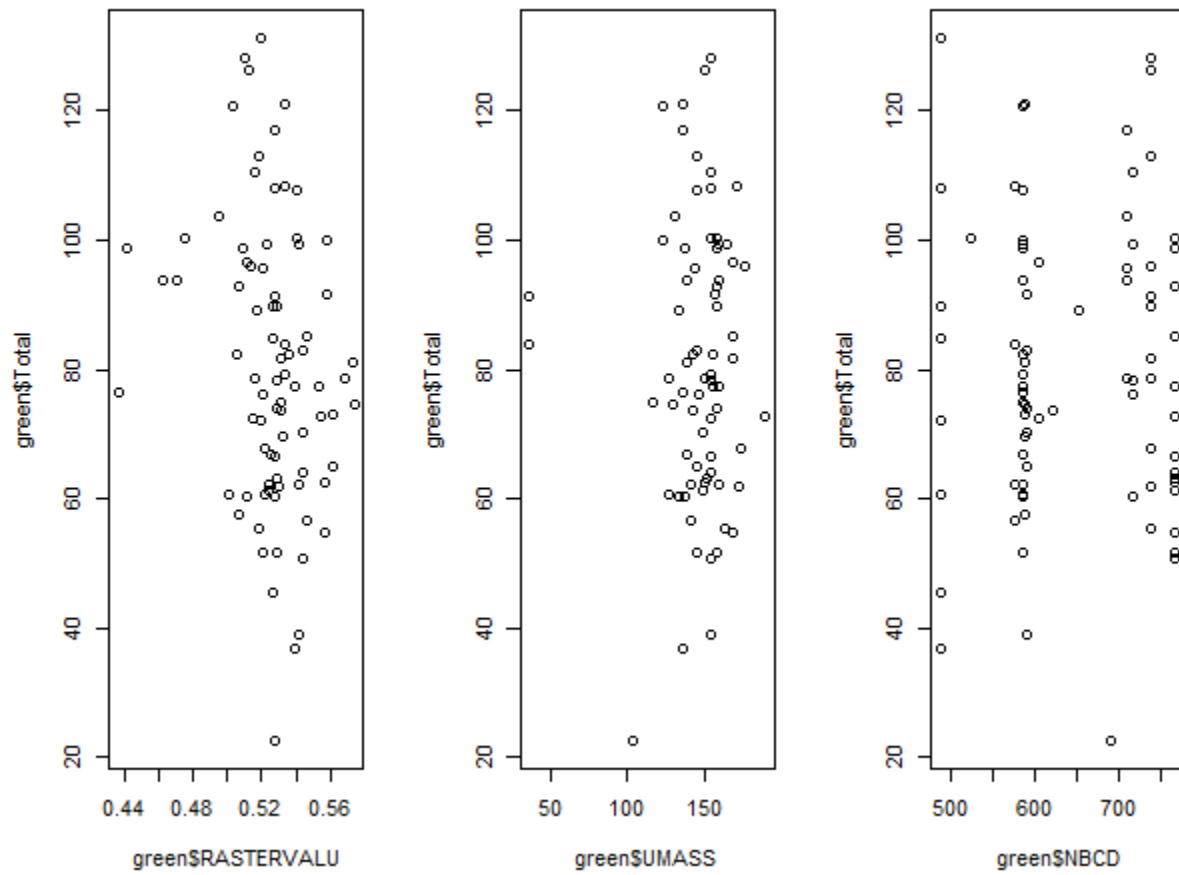


Appendix 9. NPS vegetation reclassification -total mixed biomass (tons/acre) by NDVI, UMASS, and NBCD raster values.

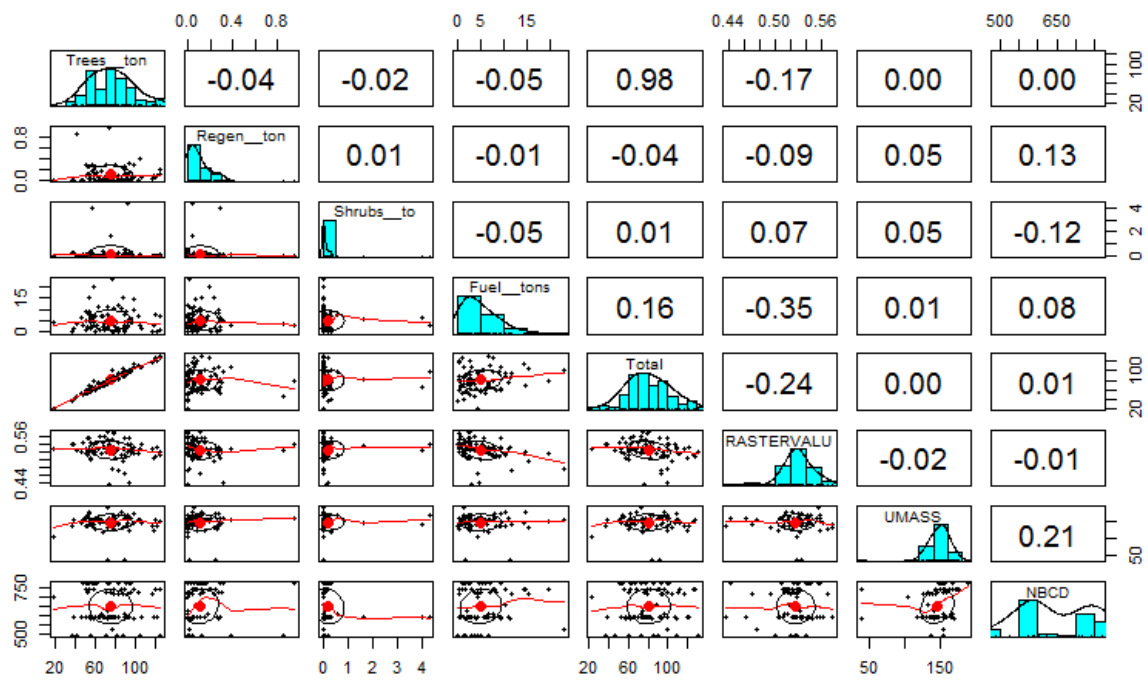


Appendix 10. NPS vegetation reclassification – Vertical structure of mixed biomass (tons/acre) by satellite imagery options (NDVI of Landsat 8 image, UMASS Biomass, and National Biomass and Carbon Dataset).

Deciduous:



Appendix 11. NPS vegetation reclassification -total deciduous biomass (tons/acre) by NDVI, UMass, and NBCD raster values.



Appendix 12. NPS vegetation reclassification – Vertical structure of deciduous biomass (tons/acre) by satellite imagery options (NDVI of Landsat 8 image, UMSS Biomass, and National Biomass and Carbon Dataset).

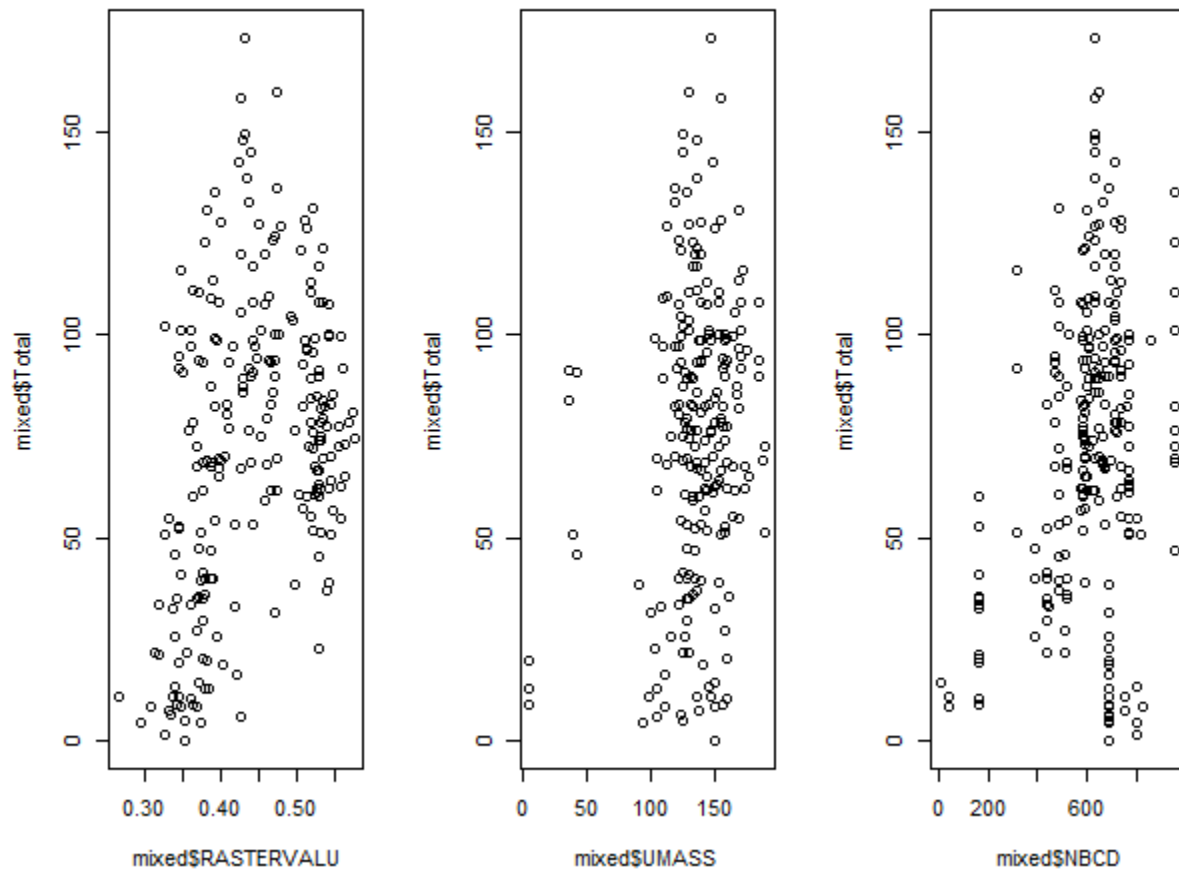
Appendix 13. Reclassification of NPS community types into 2 categories: conifer and mixed. Highlighted grey shows incorrect classifications in NPS reclassification GIS data layer.

Count of NPS_reclass Column Labels											
Row Labels	birch-aspen	cedar	mixed conifer - hardwood	mixed harwood - conifer	northern hardwood	old growth spruce	pitch pine	red oak	spruce/fir	Grand Total	
conifer	1	20	35	2	1	19	23		134	235	
mixed	39	20	5	38	39	1	17	20	57	236	
Grand Total	40	40	40	40	40	20	40	20	191	471	

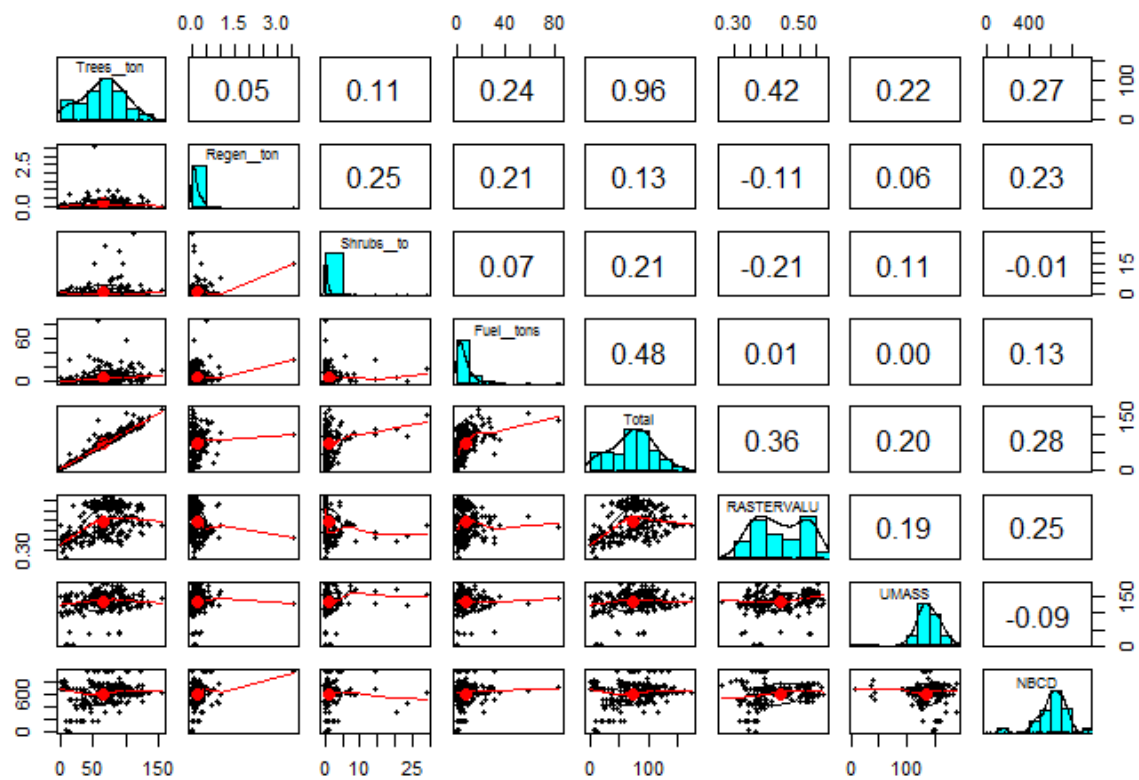
Conifer:

See 'Conifer' above as it's the same.

Mixed (mixed and green combined from above example):



Appendix 14. NPS vegetation reclassification -total mixed (mixed and green combined from above example) biomass (tons/acre) by NDVI, UMass, and NBCD raster values.



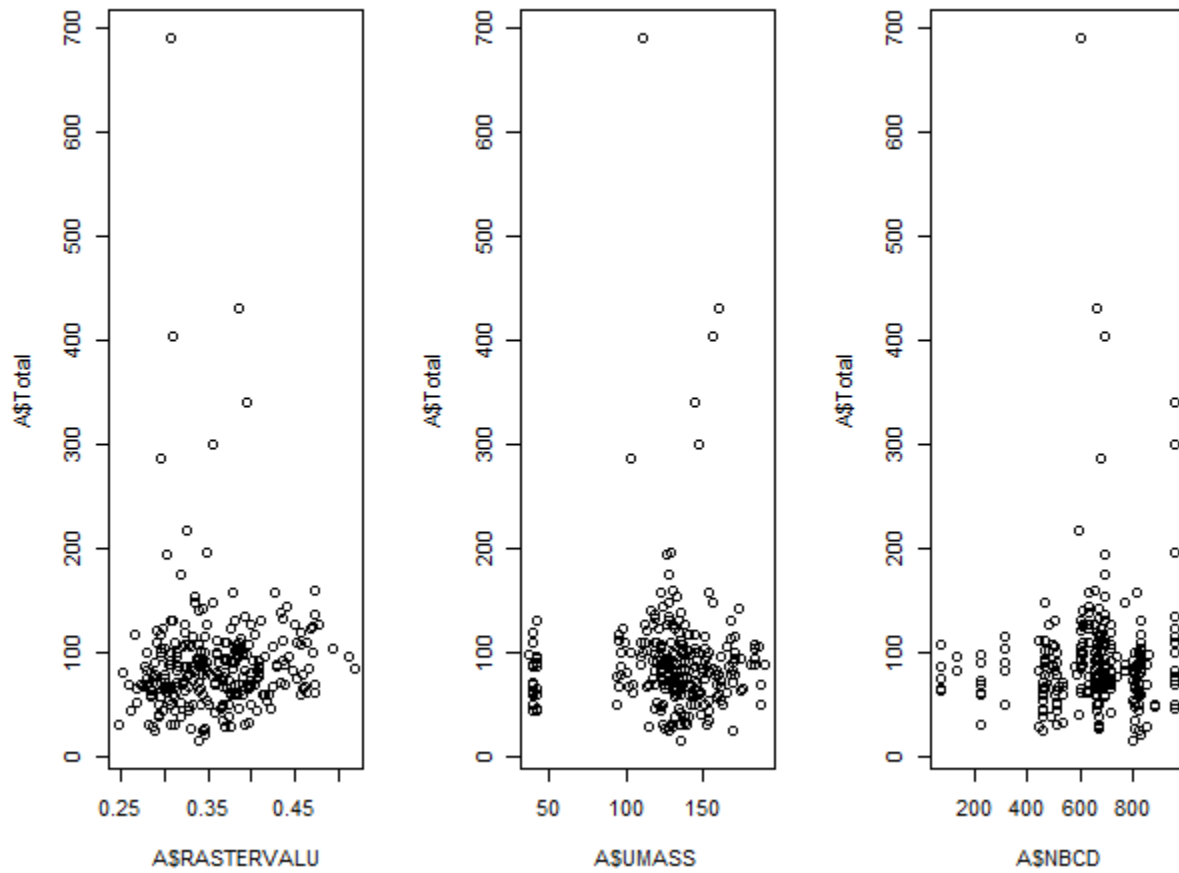
Appendix 15. NPS vegetation reclassification – Vertical structure of mixed (green and mixed combined in above example) biomass (tons/acre) by satellite imagery options (NDVI of Landsat 8 image, UMSS Biomass, and National Biomass and Carbon Dataset).

Appendix 16. Reclassification of NPS community types into vegetation flammability categories. Highlighted grey shows incorrect classifications in NPS reclassification GIS data layer.

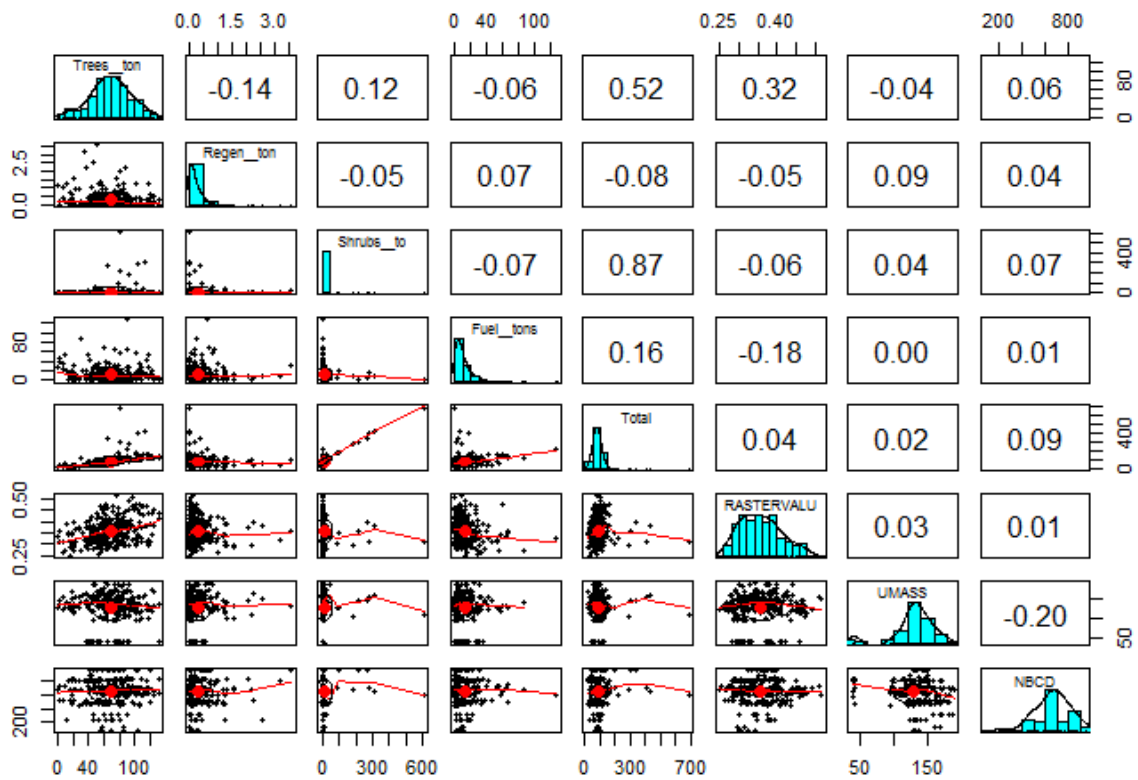
Count of FLAM_reclass		Column Labels									Grand Total
Row Labels		birch-aspen	cedar	mixed conifer - hardwood	mixed harwood - conifer	northern hardwood	old growth spruce	pitch pine	red oak	spruce/fir (blank)	
A			20	39	34	4	19	4		150	270
B			19	20	1		1	17		41	99
C			1					19			20
D			20		6	36			20		82
Grand Total			40	40	40	40	20	40	20	191	471

A= spruce/fir/cedar; B=mixed conifer/deciduous; C=red/white/jack/pitch pine; D=birch/aspen/northern hardwoods ; E=health/grass/shrub; F=water; G=developed

A, spruce/fir/cedar:

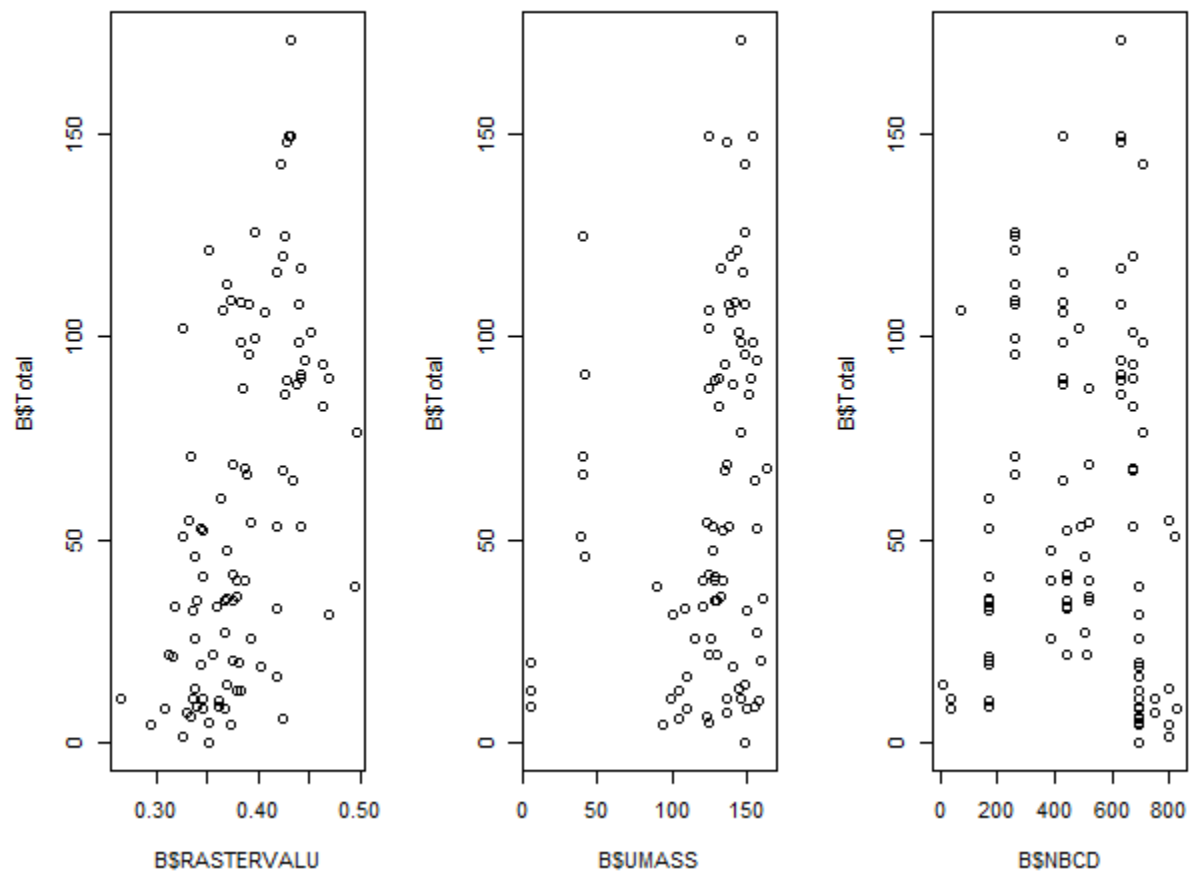


Appendix 17. NPS vegetation reclassification -total spruce/fir/cedar biomass (tons/acre) by NDVI, UMass, and NBCD raster values.

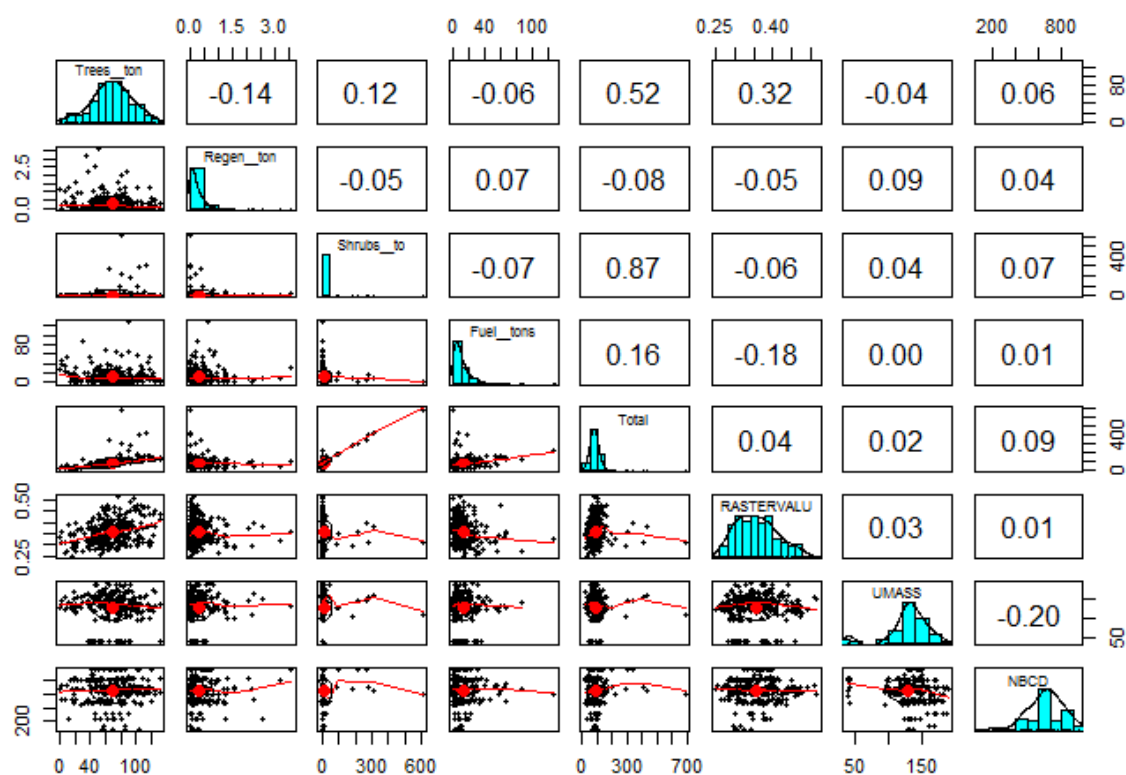


Appendix 18. NPS vegetation reclassification – Vertical structure of spruce/fir/cedar biomass (tons/acre) by satellite imagery options (NDVI of Landsat 8 image, UMASS Biomass, and National Biomass and Carbon Dataset).

B, mixed conifer/deciduous:

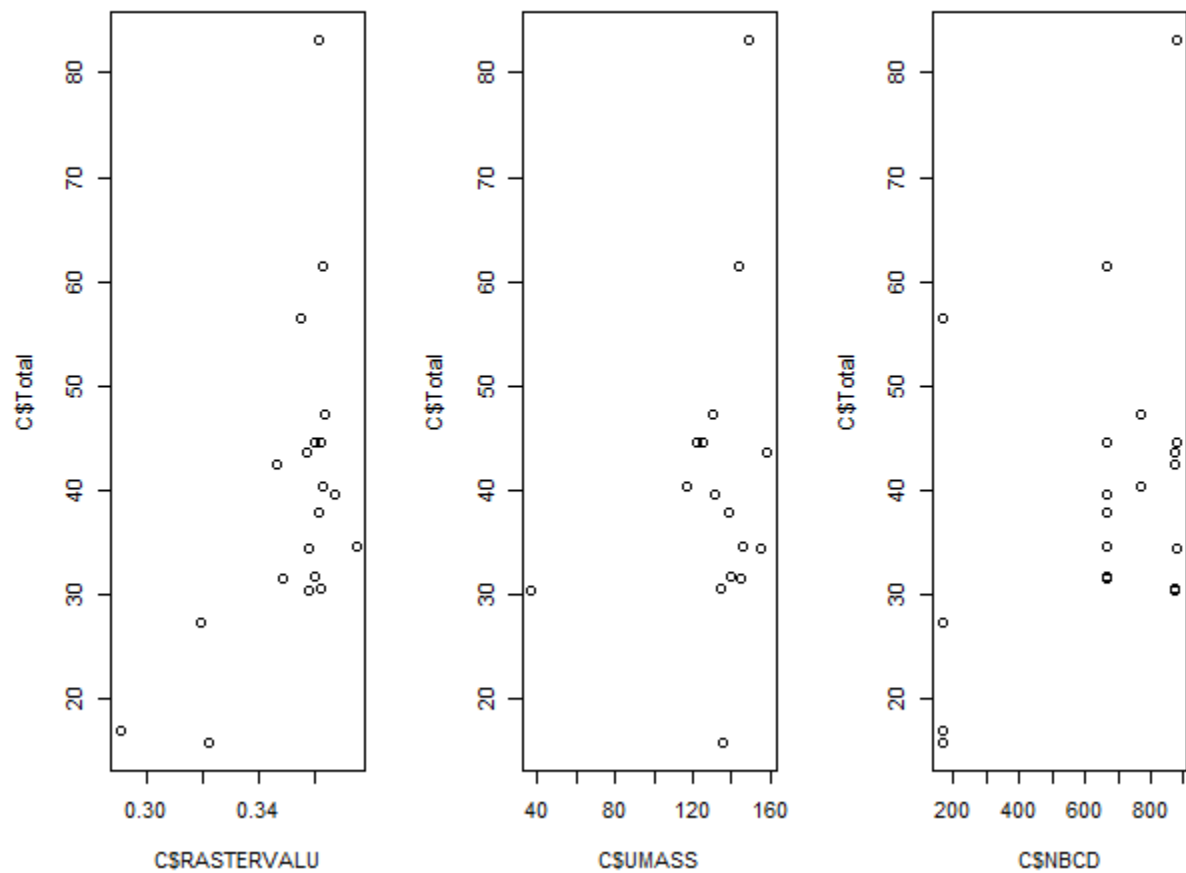


Appendix 19. NPS vegetation reclassification -total mixed conifer/deciduous biomass (tons/acre) by NDVI, UMass, and NBCD raster values.

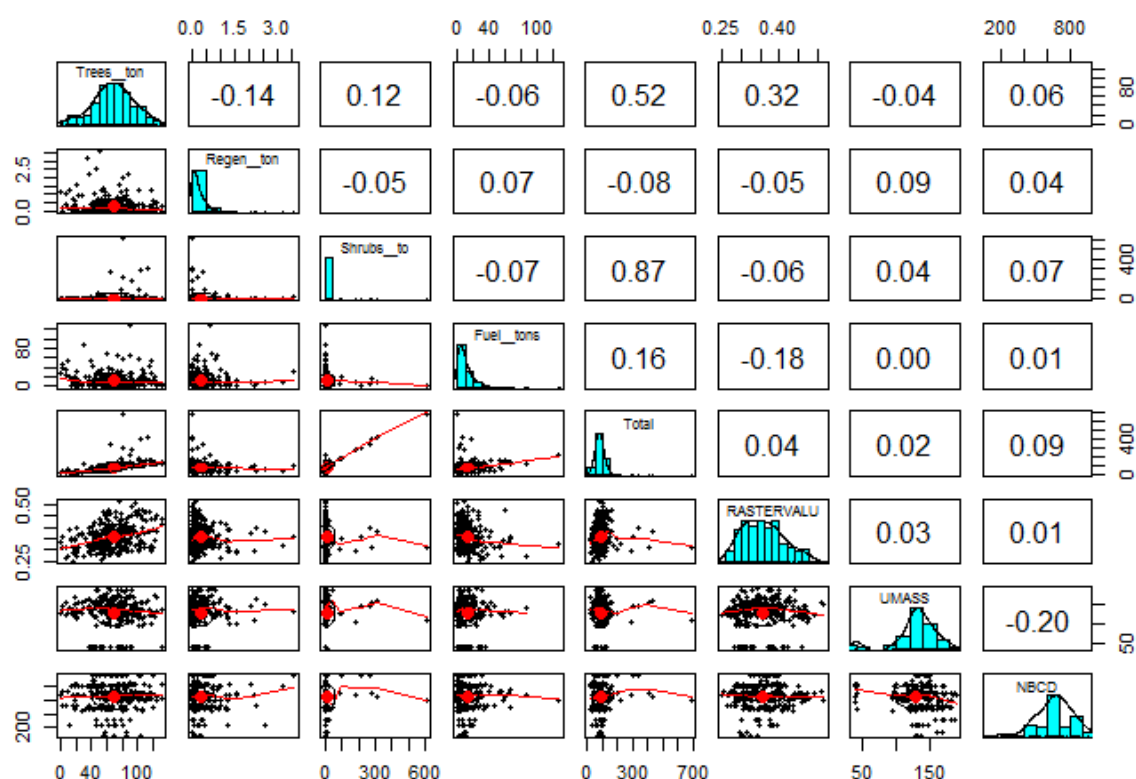


Appendix 20. NPS vegetation reclassification – Vertical structure of mixed conifer/deciduous biomass (tons/acre) by satellite imagery options (NDVI of Landsat 8 image, UMASS Biomass, and National Biomass and Carbon Dataset).

C, red/white/jack/pitch pine:

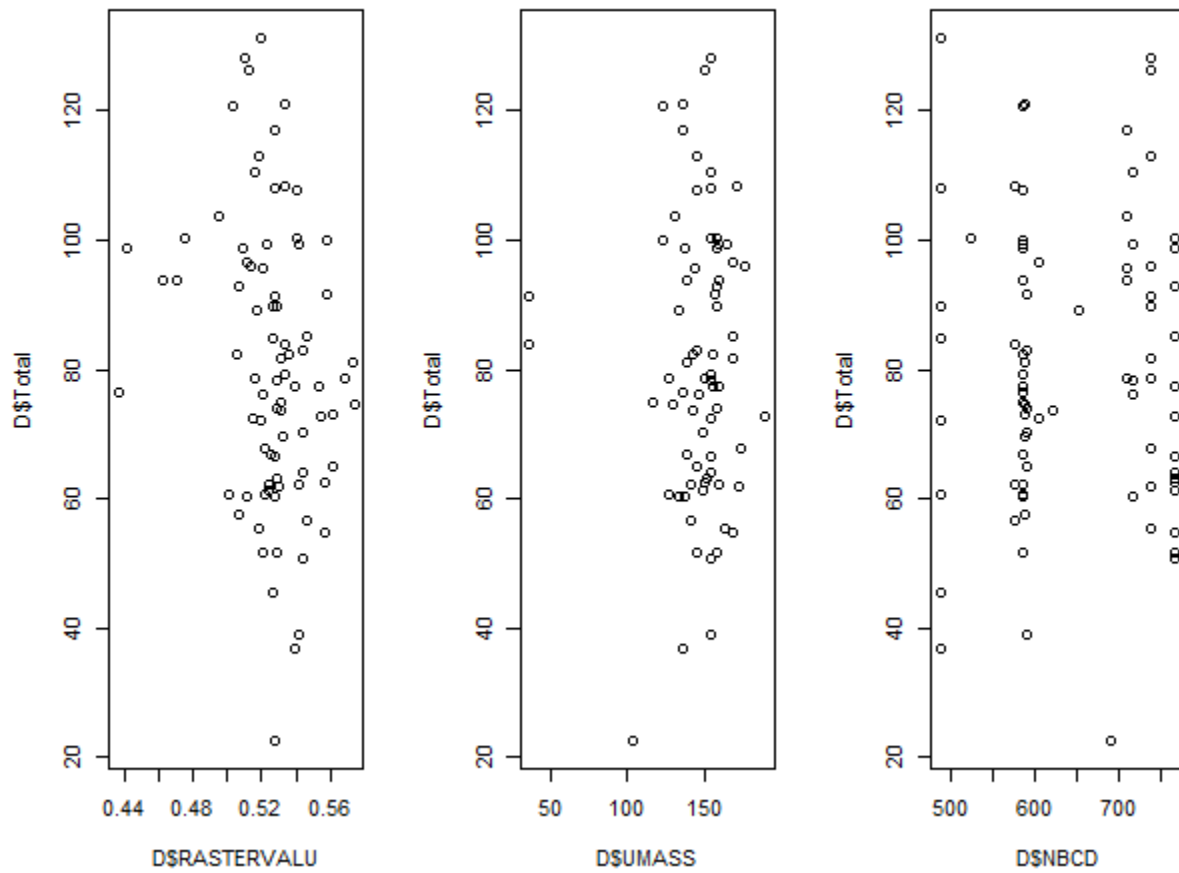


Appendix 21. NPS vegetation reclassification -total red/white/jack/pitch pine biomass (tons/acre) by NDVI, UMASS, and NBCD raster values.

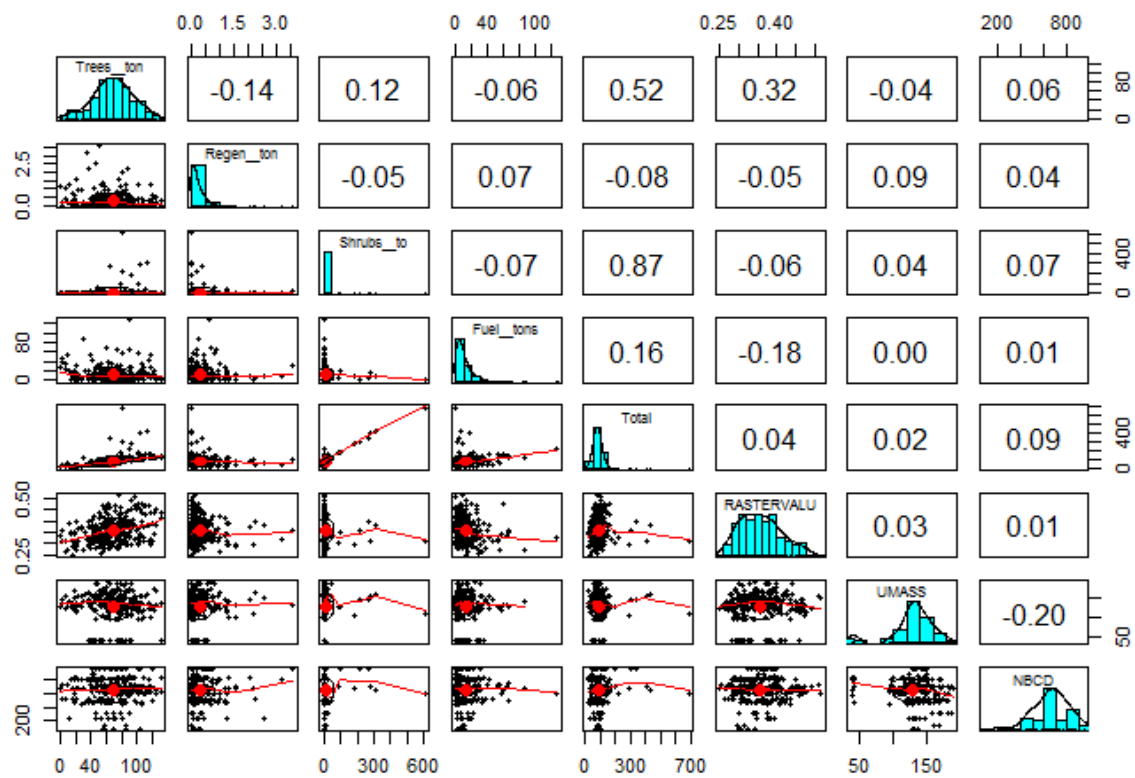


Appendix 22. NPS vegetation reclassification – Vertical structure of red/white/jack/pitch pine biomass (tons/acre) by satellite imagery options (NDVI of Landsat 8 image, UMASS Biomass, and National Biomass and Carbon Dataset).

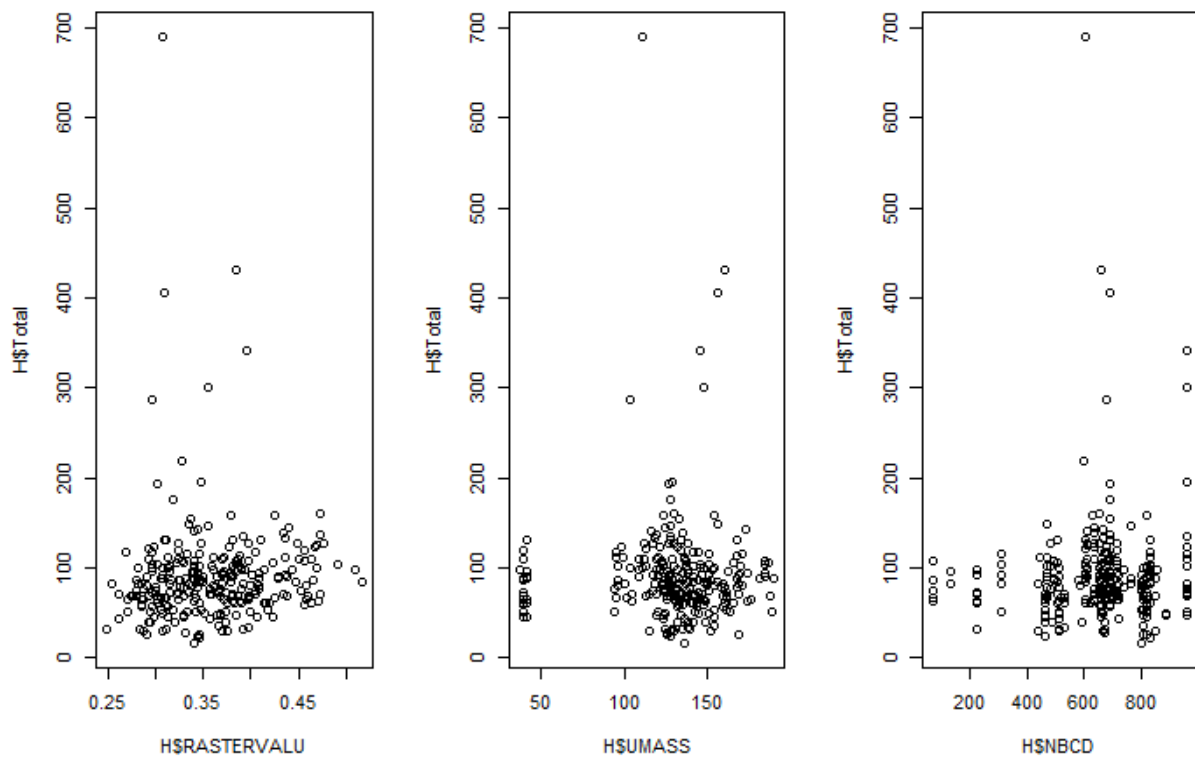
D, birch/aspen/northern hardwoods:



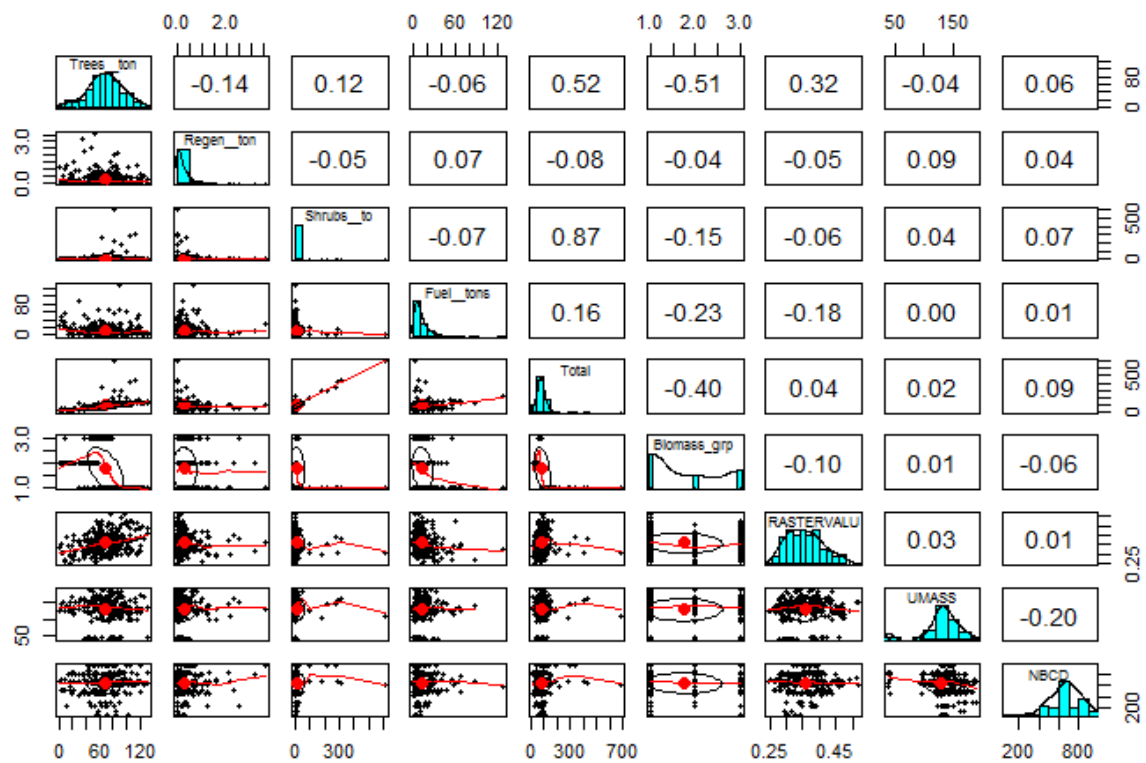
Appendix 23. NPS vegetation reclassification -total birch/aspen/northern hardwoods biomass (tons/acre) by NDVI, UMASS, and NBCD raster values.



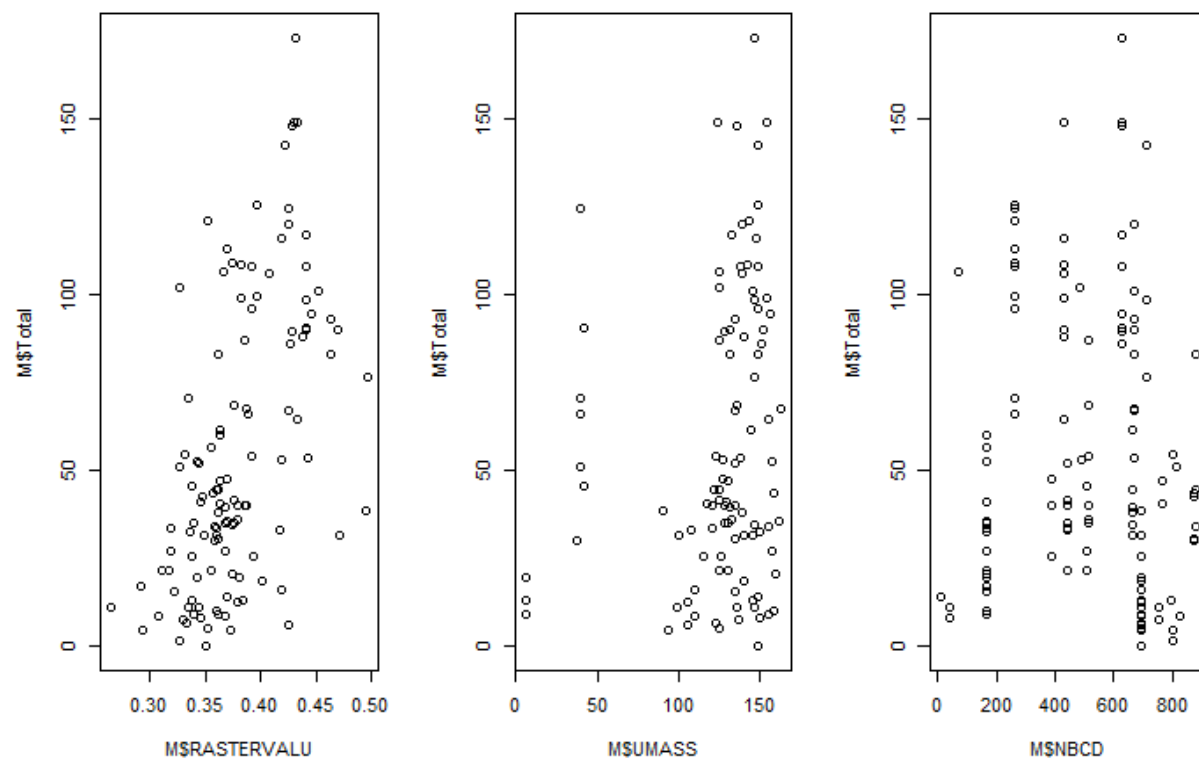
Appendix 24. NPS vegetation reclassification – Vertical structure of birch/aspen/northern hardwoods biomass (tons/acre) by satellite imagery options (NDVI of Landsat 8 image, UMASS Biomass, and National Biomass and Carbon Dataset).



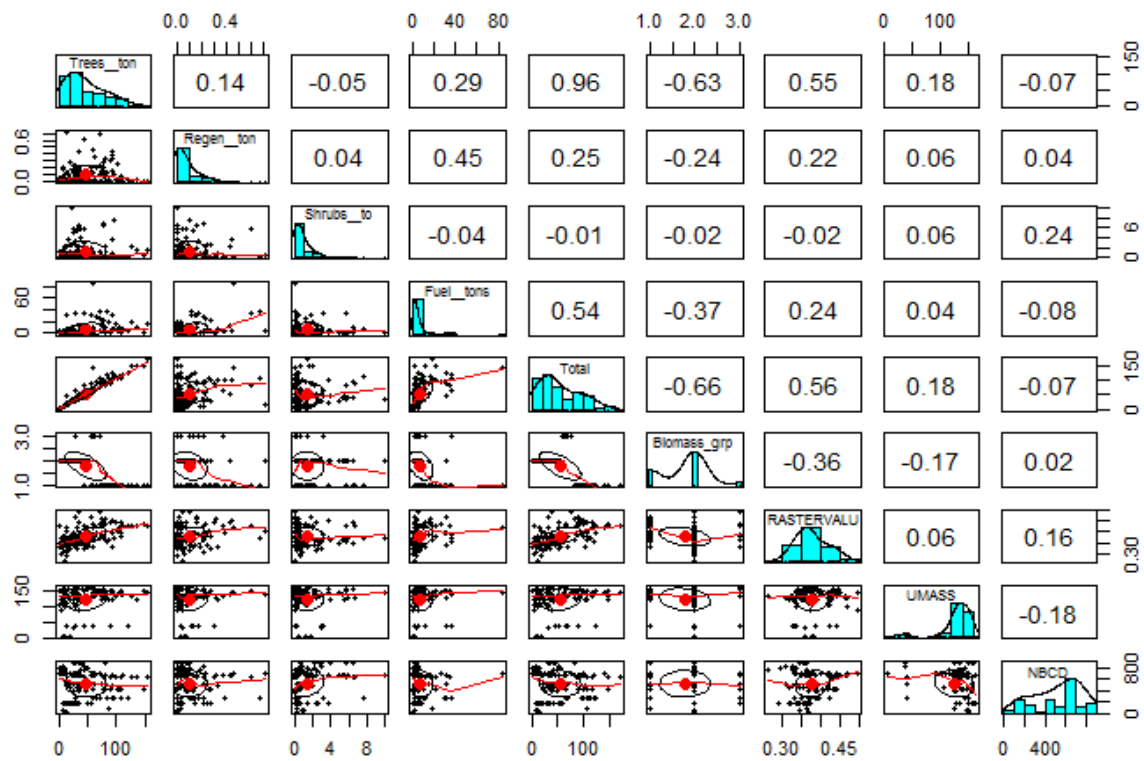
Appendix 25. NPS vegetation reclassification –high total biomass (tons/acre) by NDVI, UMass, and NBCD raster values.



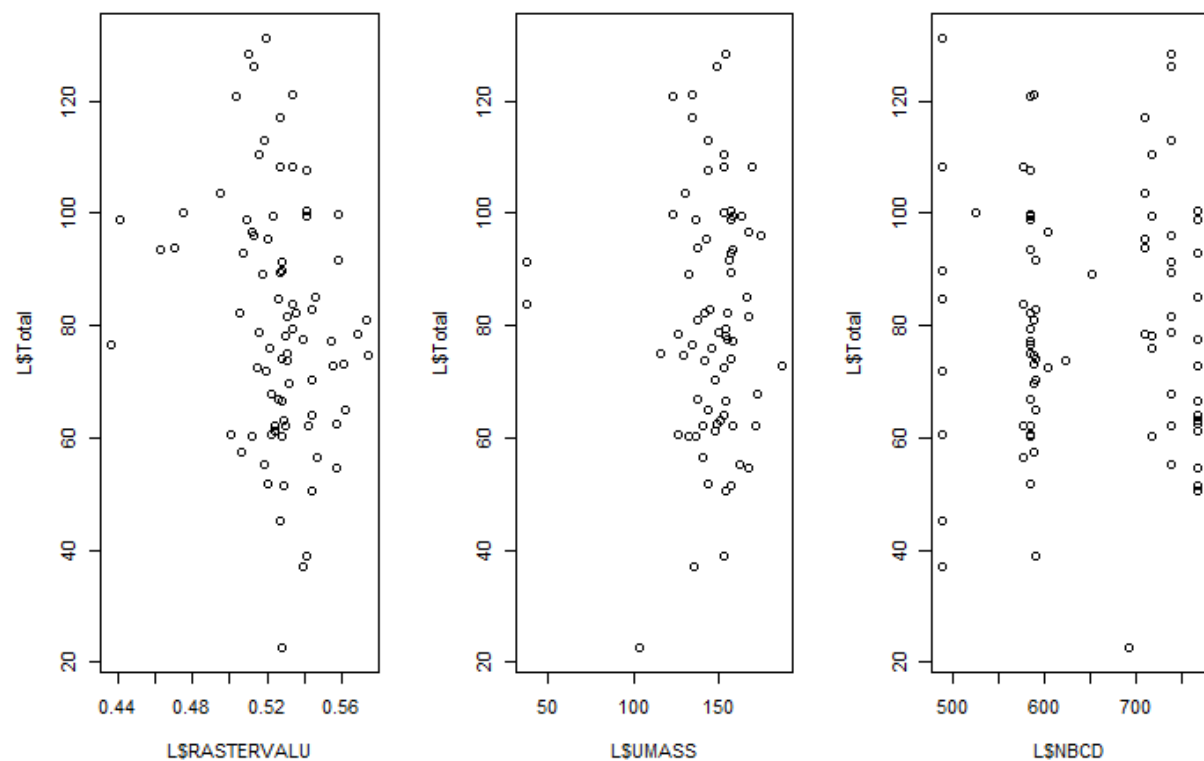
Appendix 26. NPS vegetation reclassification – Vertical structure of high total biomass (tons/acre) by satellite imagery options (NDVI of Landsat 8 image, UMass Biomass, and National Biomass and Carbon Dataset).



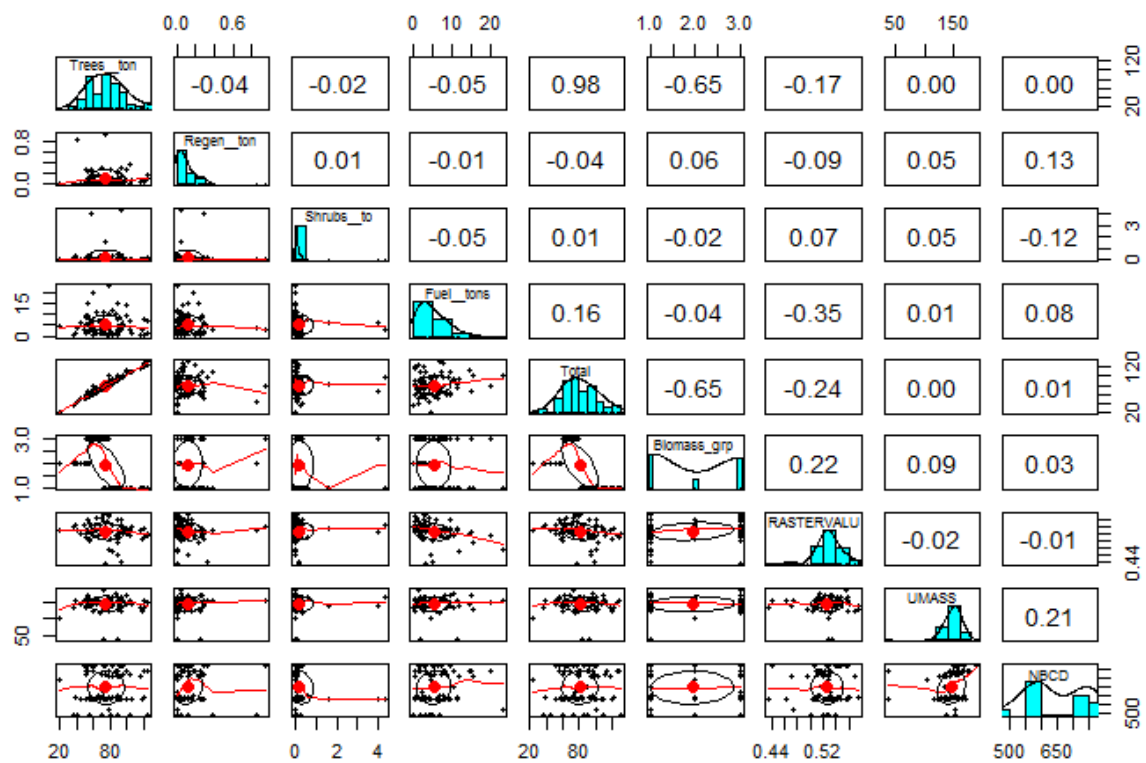
Appendix 27. NPS vegetation reclassification –medium total biomass (tons/acre) by NDVI, UMass, and NBCD raster values.



Appendix 28. NPS vegetation reclassification – Vertical structure of medium total biomass (tons/acre) by satellite imagery options (NDVI of Landsat 8 image, UMass Biomass, and National Biomass and Carbon Dataset).



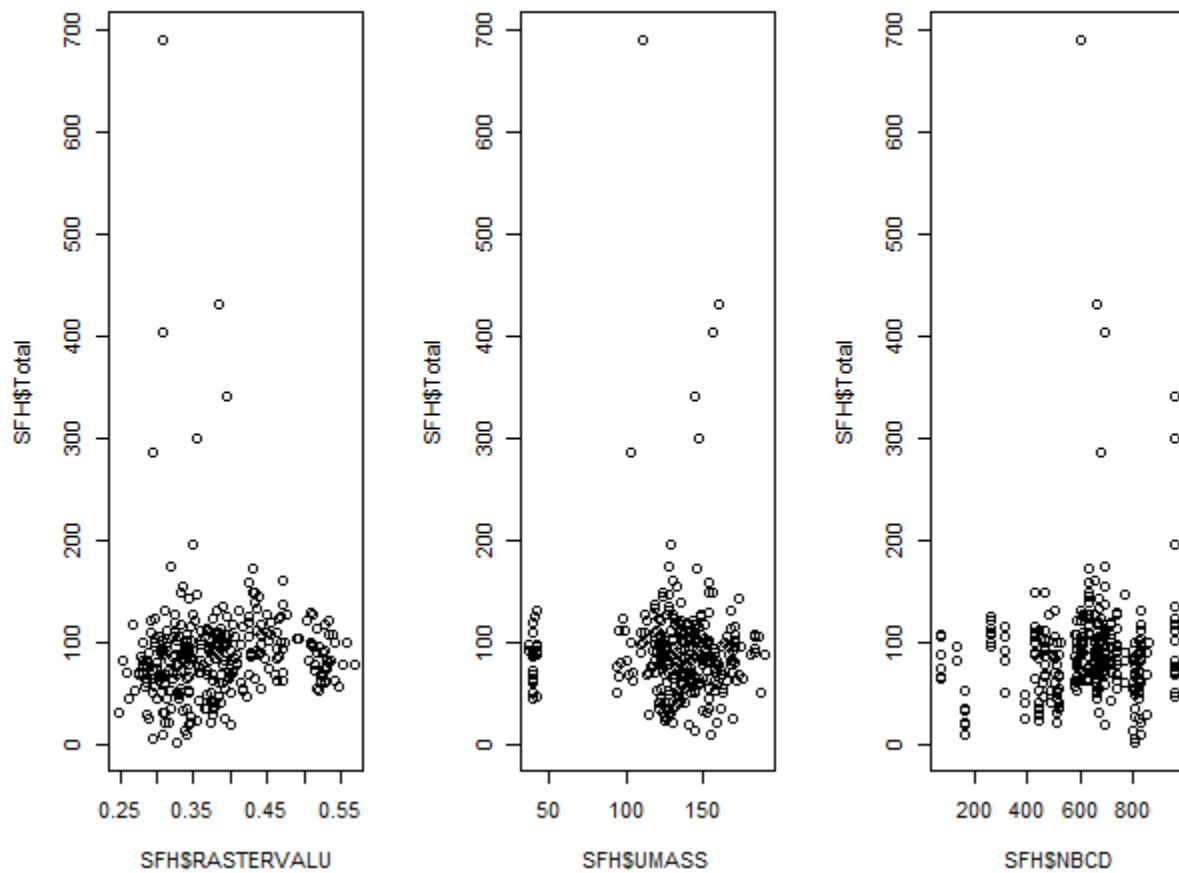
Appendix 29. NPS vegetation reclassification –low total biomass (tons/acre) by NDVI, UMass, and NBCD raster values.



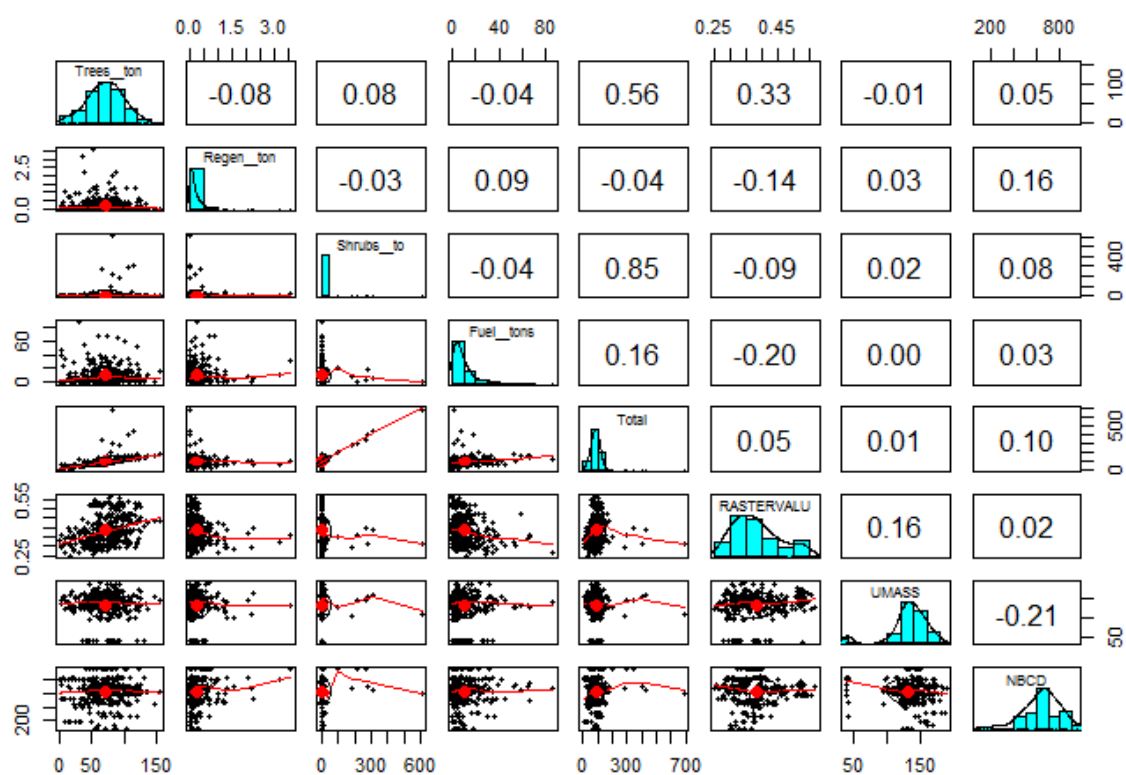
Appendix 30. NPS vegetation reclassification – Vertical structure of low total biomass (tons/acre) by satellite imagery options (NDVI of Landsat 8 image, UMass Biomass, and National Biomass and Carbon Dataset).

Appendix 31. TNC vegetation community types by communities as identified in the field. Highlighted grey shows incorrect classifications in TNC GIS data layer.

Count of Community Type	Column Labels										
Row Labels	birch-aspen	cedar	mixed conifer - hardwood	mixed harwood - conifer	northern hardwood	old growth spruce	pitch pine	red oak	spruce/fir	Grand Total	
Acadian Low Elevation Spruce-Fir-Hardwood Forest	2	14	38	37	36	10	8	2	173	320	
Acadian Sub-boreal Spruce Flat		5	1	3			19			28	
Acidic Cliff and Talus		10				9				19	
Acidic Rocky Outcrop						1				1	
Developed	1	10	1		2		3		16	33	
Laurentian-Acadian Northern Hardwood Forest	22						1	8		31	
Laurentian-Acadian Red Oak-Northern Hardwood Forest	15	1			2		9	10		37	
Northern Appalachian-Acadian Conifer-Hardwood Acidic Swamp									2	2	
Grand Total	40	40	40	40	40	20	40	20	191	471	

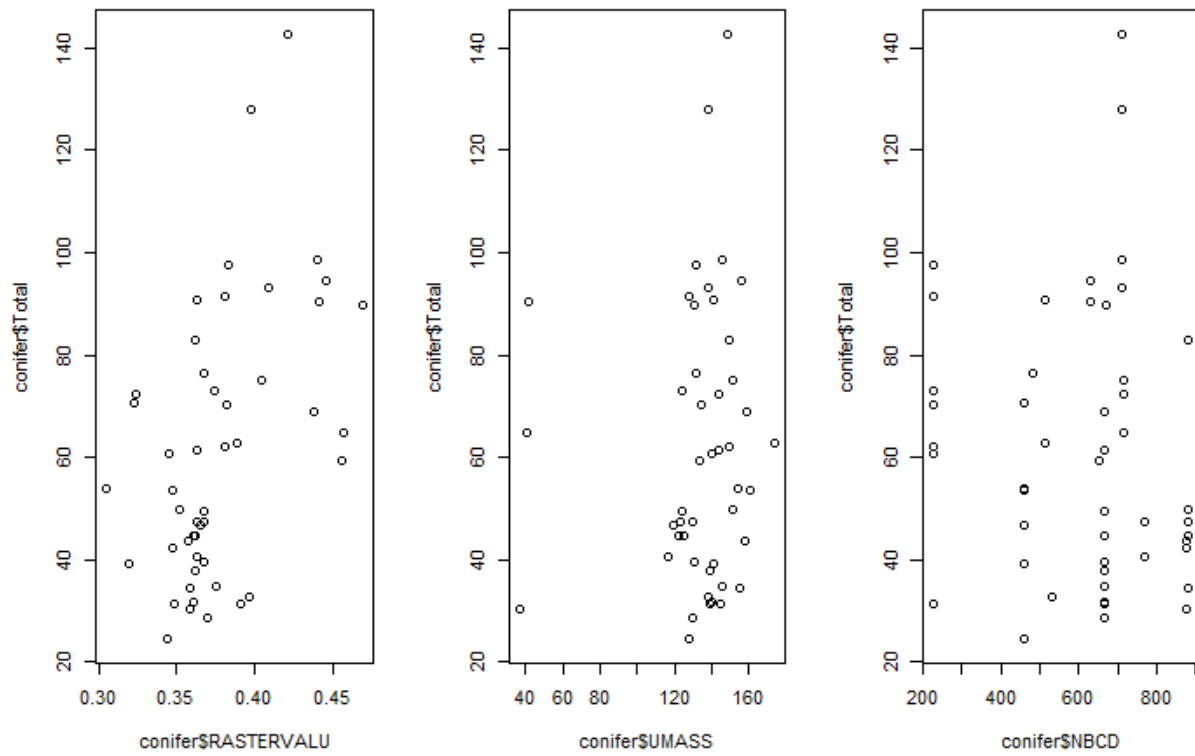


Appendix 32. TNC vegetation classification -total spruce-fir hardwood biomass (tons/acre) by NDVI, UMASS, and NBCD raster values (n=320 plots, only TNC category with a large enough plot n).

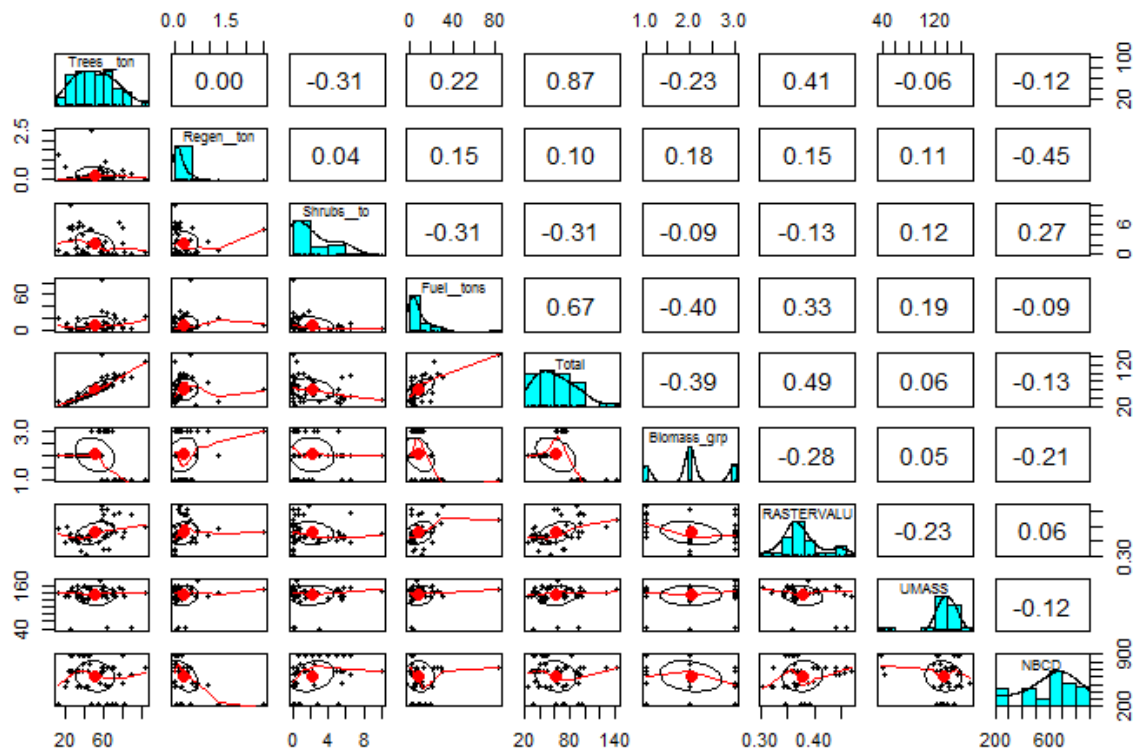


Appendix 33. TNC spruce-fir hardwood vegetation classification - All vertical structure biomass (tons/acre) by satellite imagery options (NDVI of 2016 Landsat 8 image, UMASS Biomass, and National Biomass and Carbon Dataset).

Conifer:

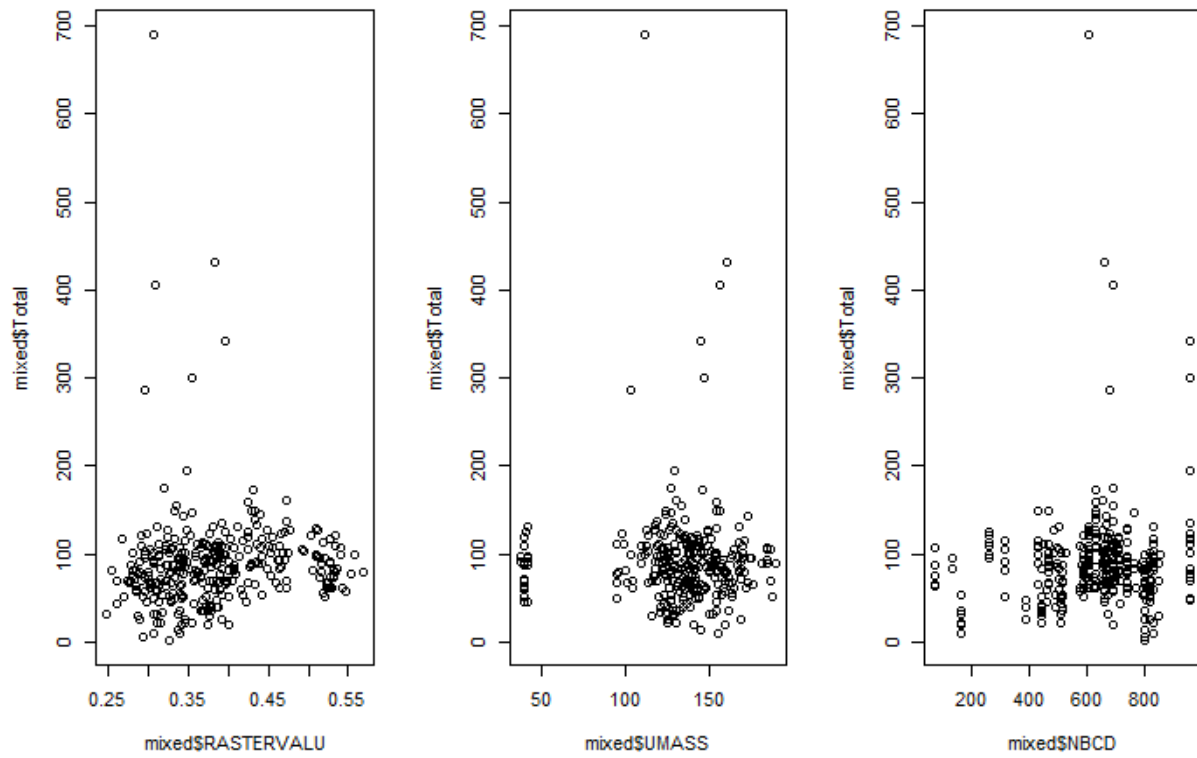


Appendix 34. TNC vegetation reclassification -conifer biomass (tons/acre) by NDVI, UMASS, and NBCD raster values.

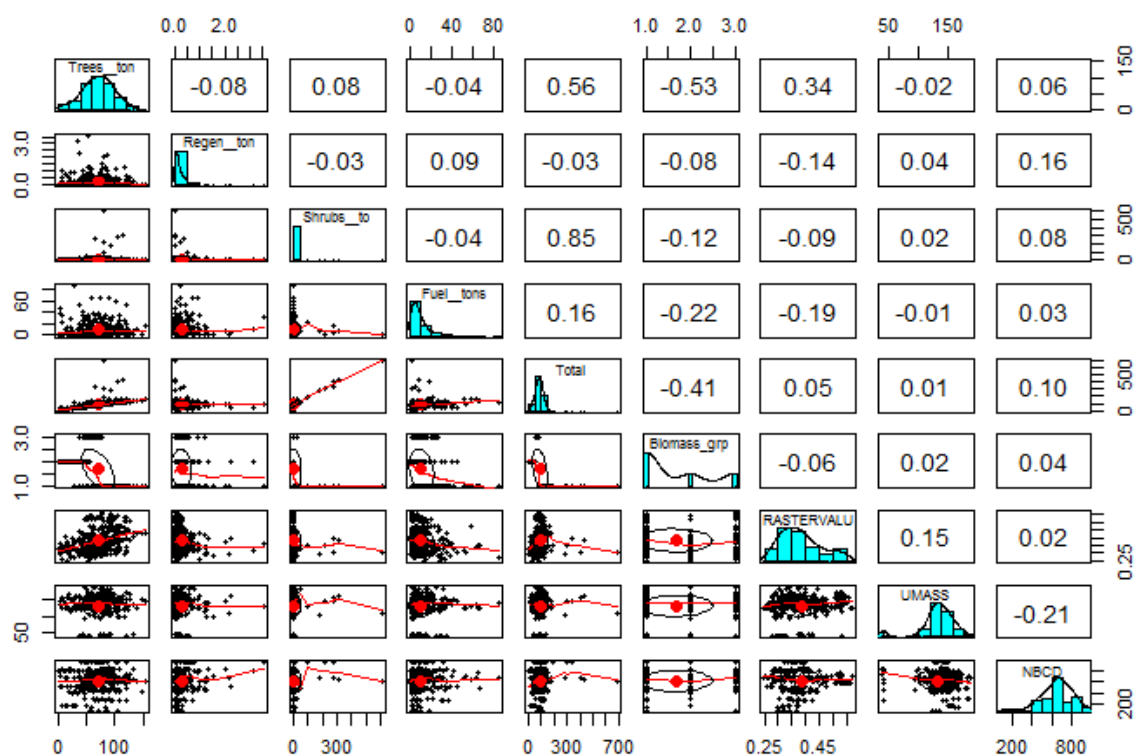


Appendix 35. TNC conifer vegetation reclassification - All vertical structure biomass (tons/acre) by satellite imagery options (NDVI of 2016 Landsat 8 image, UMass Biomass, and National Biomass and Carbon Dataset).

Mixed:

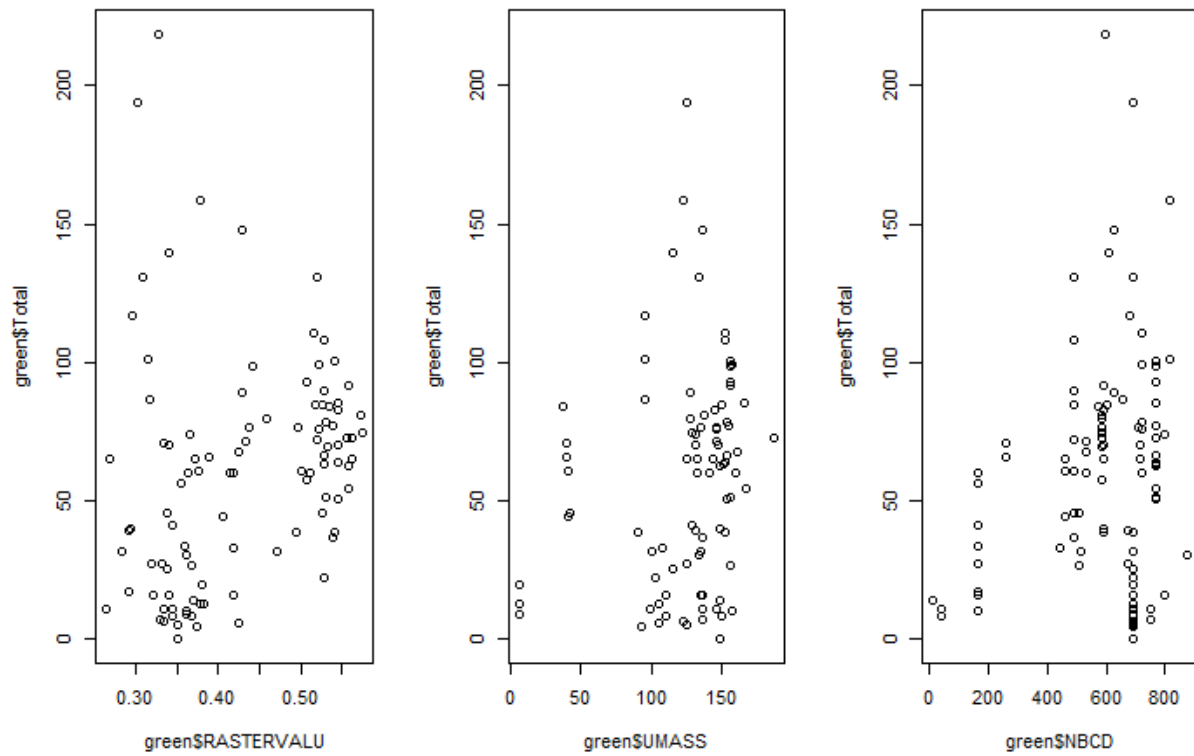


Appendix 36. TNC vegetation reclassification -mixed biomass (tons/acre) by NDVI, UMASS, and NBCD raster values.

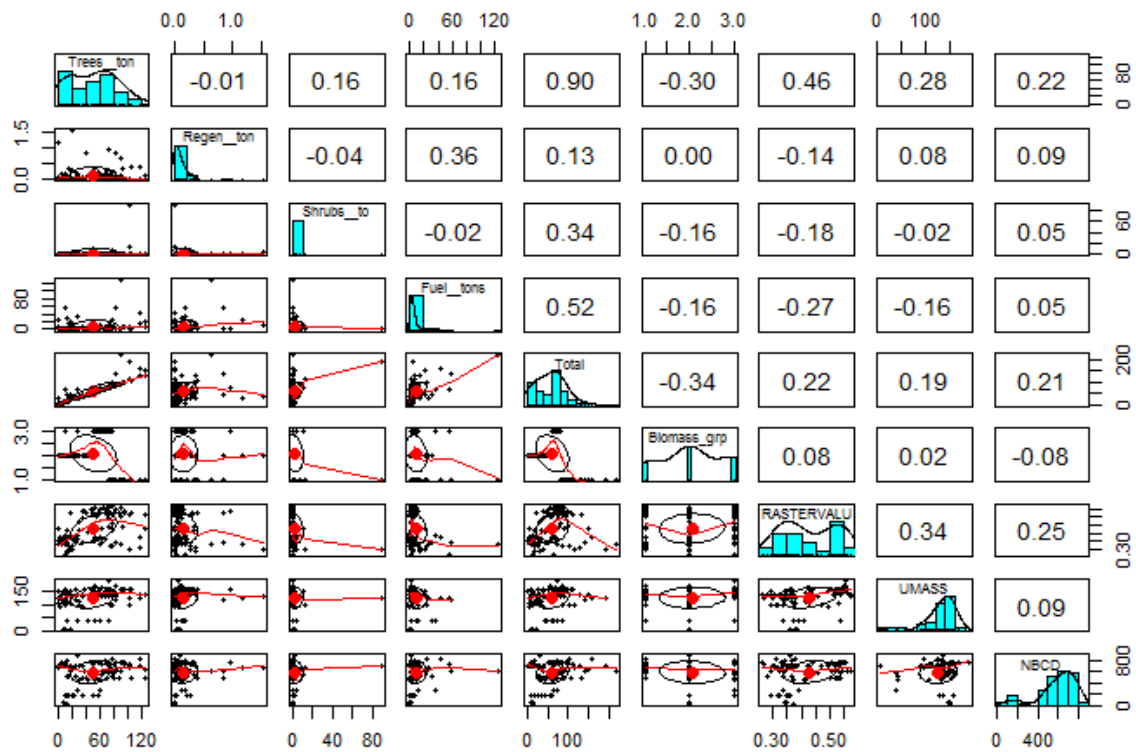


Appendix 37. TNC mixed vegetation reclassification - All vertical structure biomass (tons/acre) by satellite imagery options (NDVI of 2016 Landsat 8 image, UMass Biomass, and National Biomass and Carbon Dataset).

Deciduous:



Appendix 38. TNC vegetation reclassification -deciduous biomass (tons/acre) by NDVI, UMASS, and NBCD raster values.



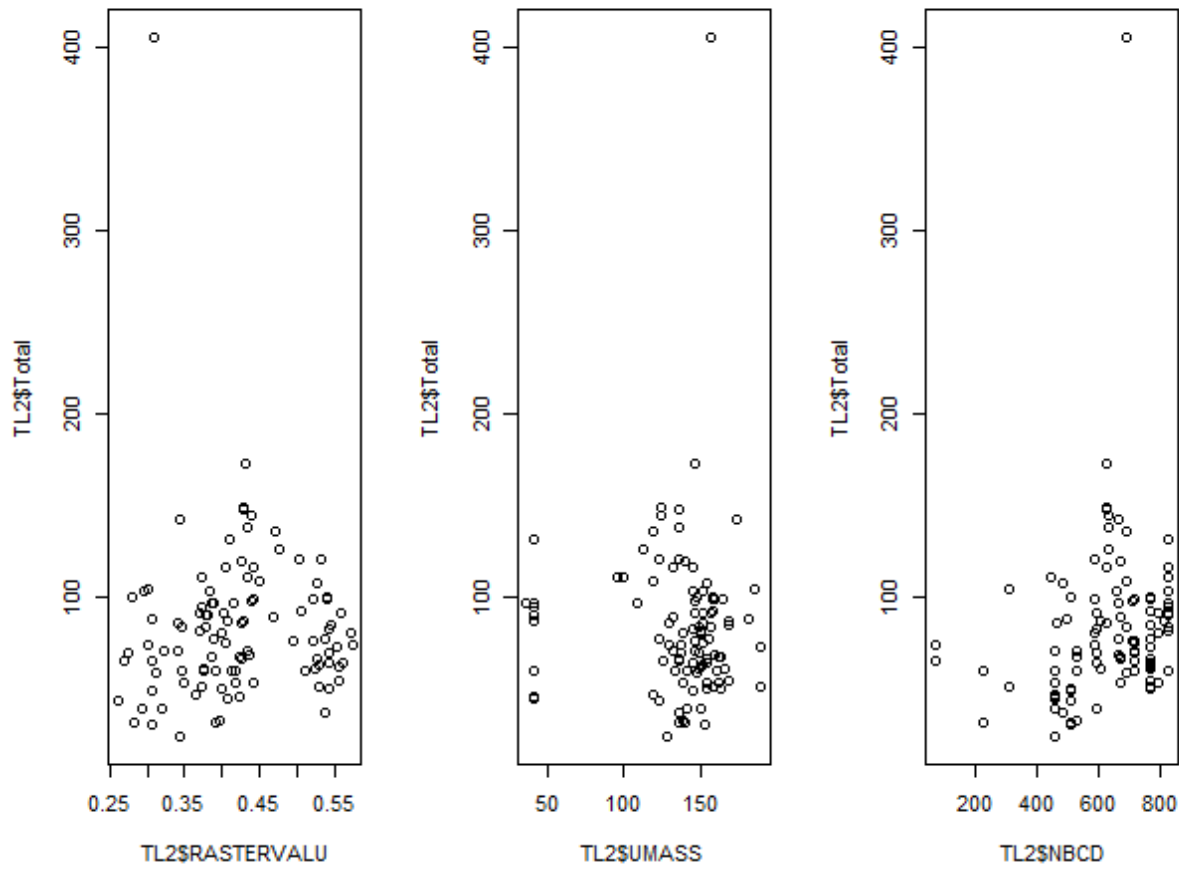
Appendix 39. TNC deciduous vegetation reclassification - All vertical structure biomass (tons/acre) by satellite imagery options (NDVI of 2016 Landsat 8 image, UMass Biomass, and National Biomass and Carbon Dataset).

Appendix 40. Scott and Burgan 40 Fuel Models (LANDFIRE data) by community types as identified in the field. Some of these are not correct but which ones are unknown. This is in-part the point of mapping the biomass, to improve this Scott and Burgan 40 Fuel Models data layer for ANP.

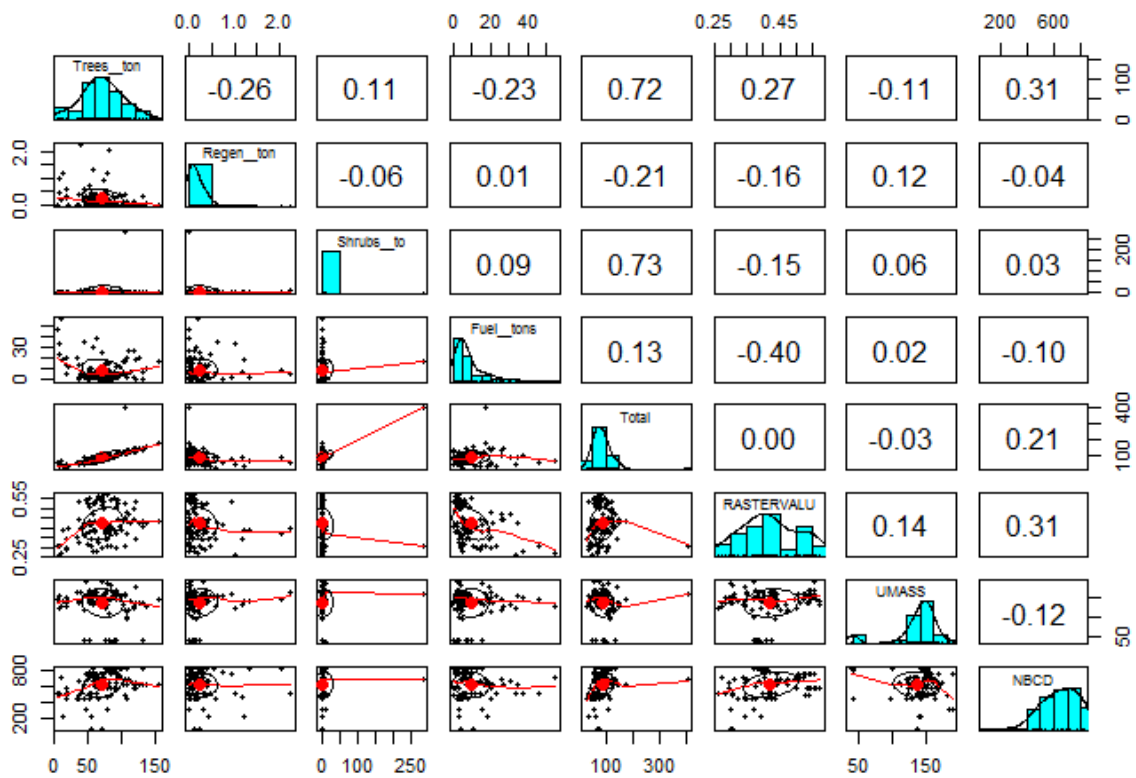
Count of SB_CT Column Labels											
Row Labels	birch-aspen	cedar	mixed conifer - hardwood	mixed hardwood - conifer	northern hardwood	old growth spruce	pitch pine	red oak	spruce/fir	Grand Total	
GS1			1				2			3	
GS3						2	2			4	
NB1	2	3	1		1			1	3	11	
SH3		1	3		8	2	5			19	
TL2	8	27	8	7	2	3		18	32	105	
TL3	17		10	6	2	7	9		24	75	
TL5	10	5	13	27	9	1	19		115	199	
TL6		3			3	1		1		8	
TU1	3	1	2			5	1		9	21	
TU3			2		13	1	2		8	26	
Grand Total	40	40	40	40	40	20	40	20	191	471	

GS=Grass Shrub; NB= Non Burnable; SH= Shrub; TL=Timber Litter; TU=Timber Understory

TL2:

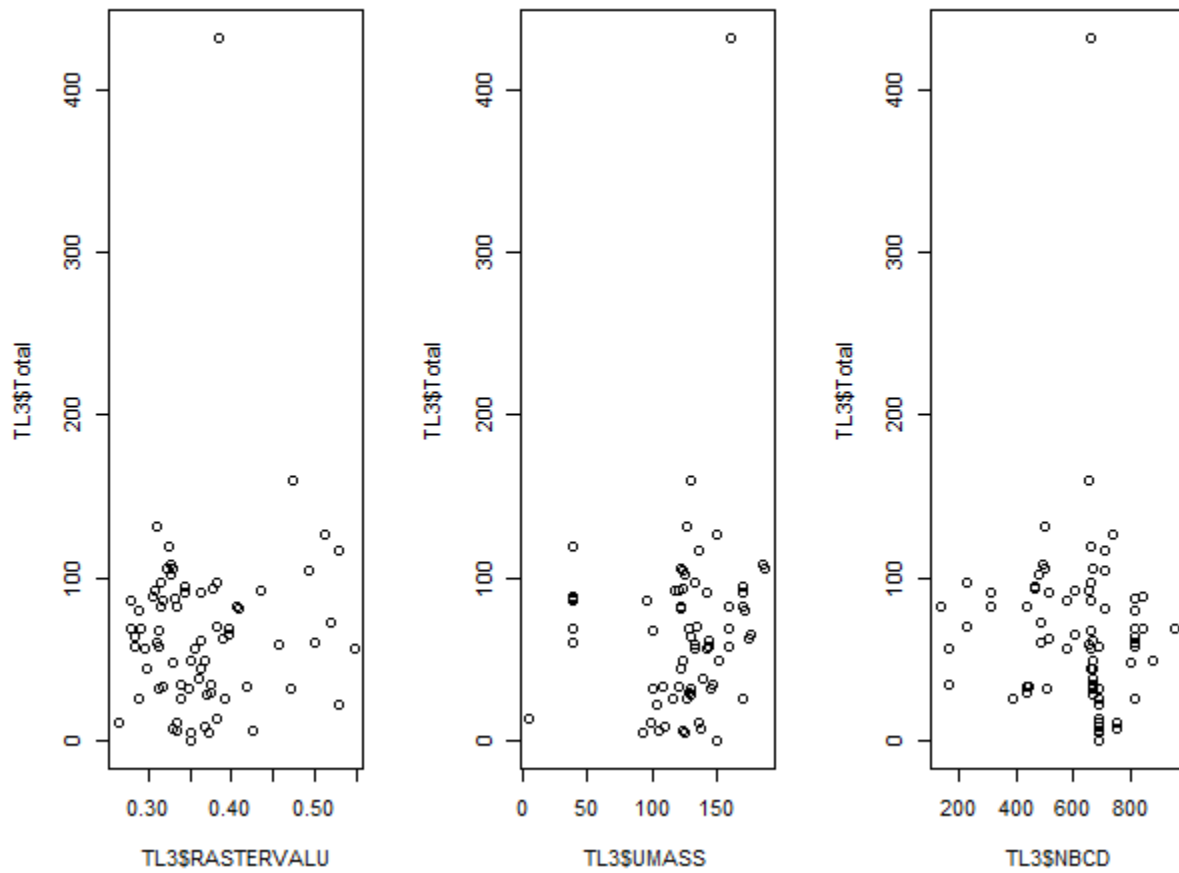


Appendix 41. Landfire: Scott and Burgan Fuel Model classifications –TL2 total biomass (tons/acre) by NDVI, UMASS, and NBCD raster values.

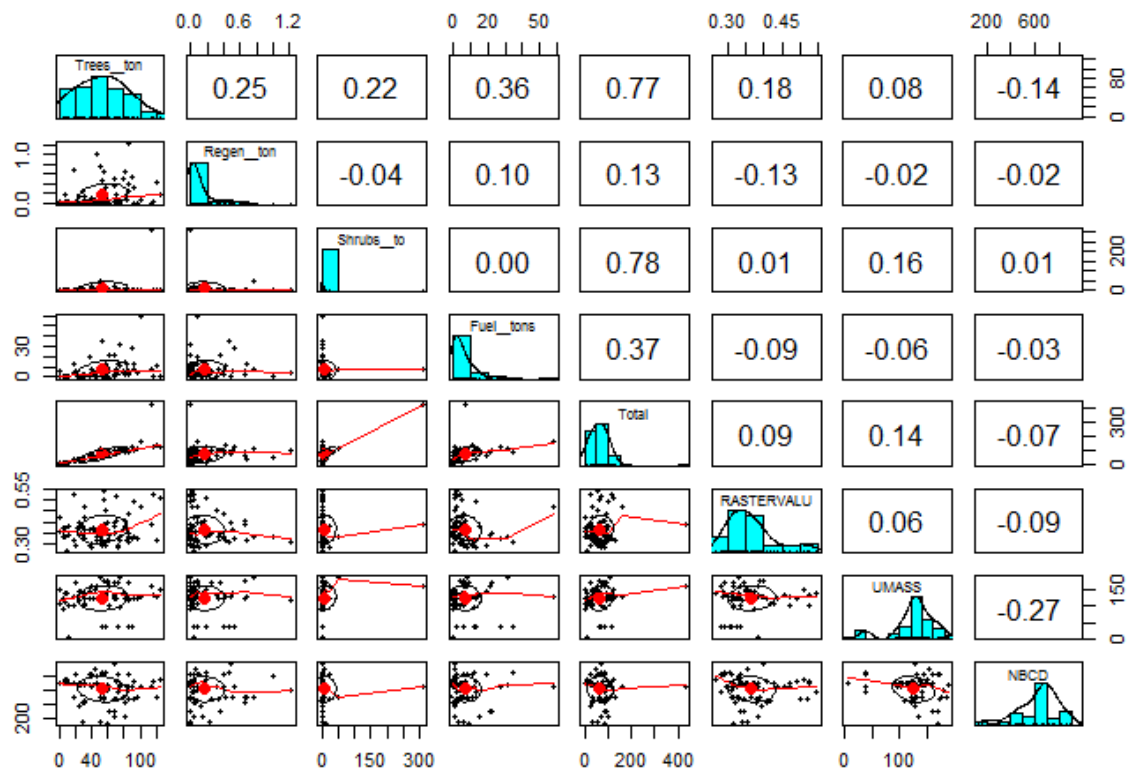


Appendix 42. Landfire: Scott and Burgan Fuel Model classifications – Vertical structure of TL2 total biomass (tons/acre) by satellite imagery options (NDVI of Landsat 8 image, UMASS Biomass, and National Biomass and Carbon Dataset).

TL3:

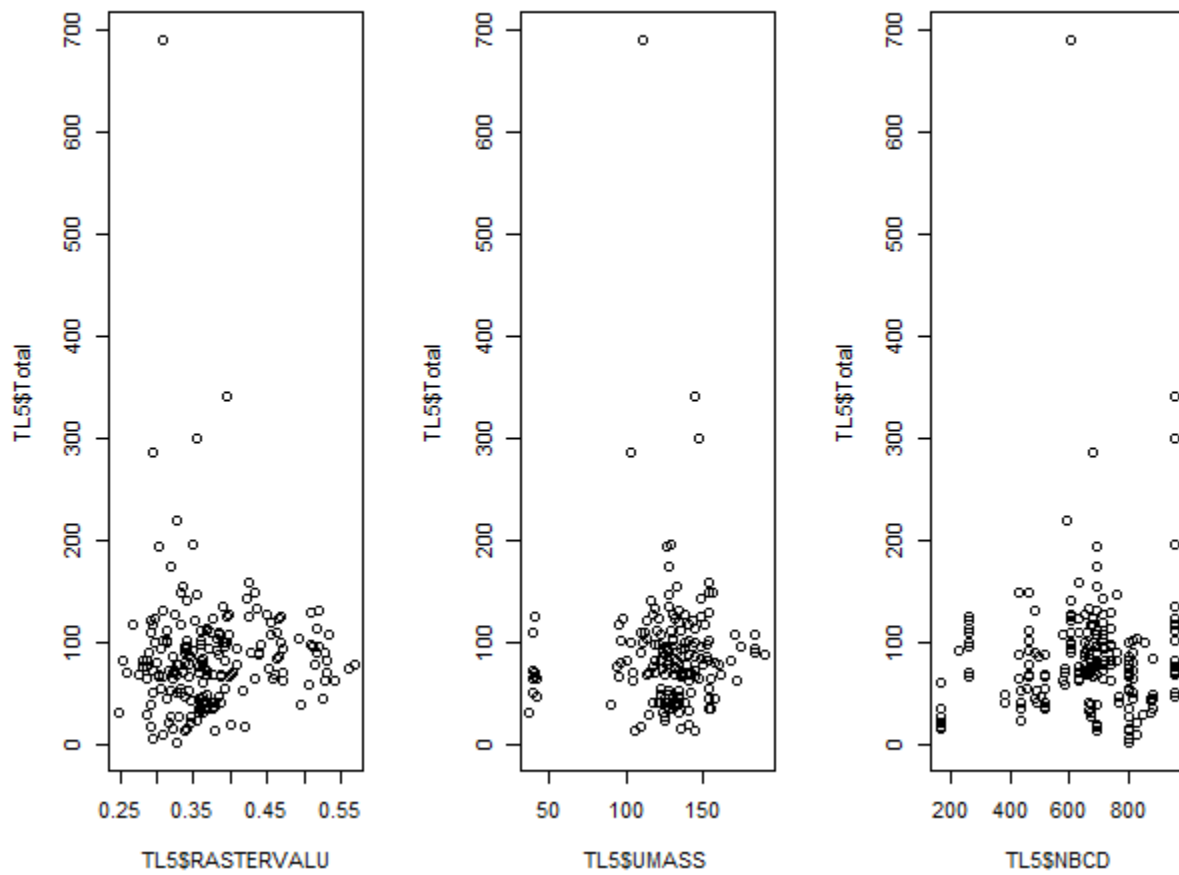


Appendix 43. Landfire: Scott and Burgan Fuel Model classifications –TL3 total biomass (tons/acre) by NDVI, UMASS, and NBCD raster values.

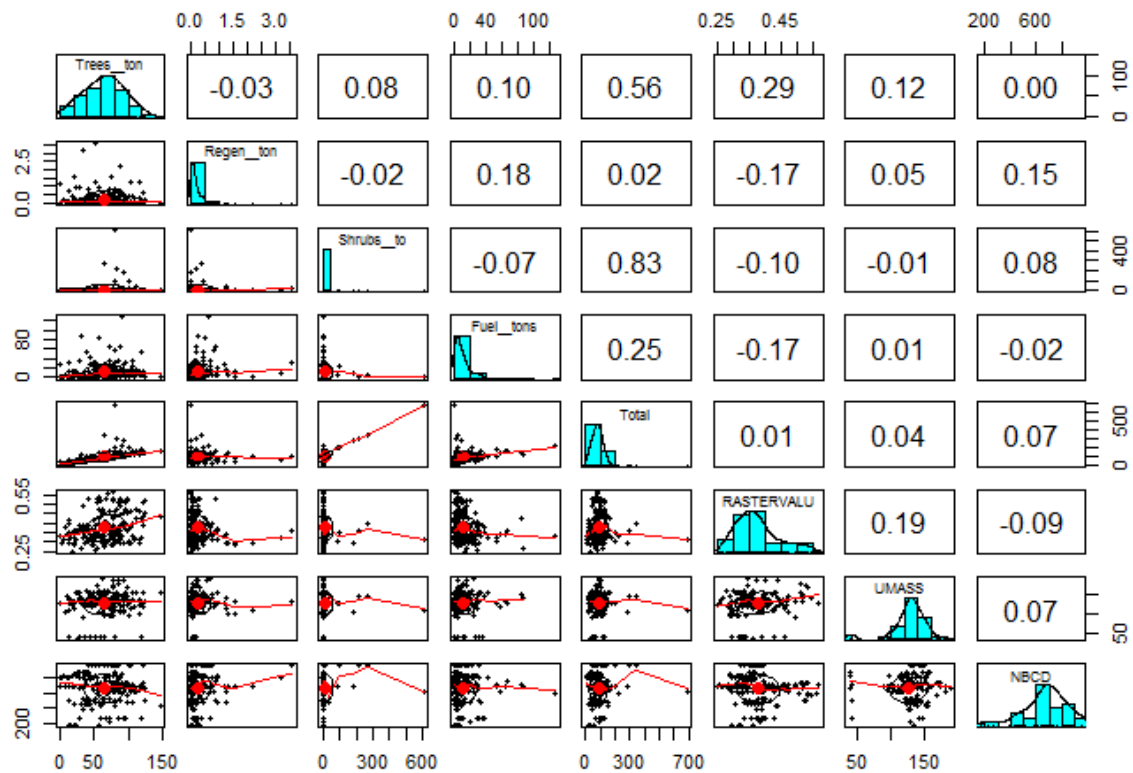


Appendix 44. Landfire: Scott and Burgan Fuel Model classifications – Vertical structure of TL3 total biomass (tons/acre) by satellite imagery options (NDVI of Landsat 8 image, UMASS Biomass, and National Biomass and Carbon Dataset).

TL5:



Appendix 45. Landfire: Scott and Burgan Fuel Model classifications –TL5 total biomass (tons/acre) by NDVI, UMASS, and NBCD raster values.



Appendix 46. Landfire: Scott and Burgan Fuel Model classifications – Vertical structure of TL5 total biomass (tons/acre) by satellite imagery options (NDVI of Landsat 8 image, UMASS Biomass, and National Biomass and Carbon Dataset).

Sample size (n) was too small for statistical inference in the remaining categories: TL6, TU1, TU3, GS1, GS3, NB1, and SH3.

