

Optimal drone-borne sensor networks for mapping plant species and plant functional types in Midwestern grasslands

Emma Hall ^{1*}, Mark J. Lara ^{1,2}

Supplemental Information

Sensor-data-fusion product confusion matrix tables for plant species and plant functional types (PFTs)

Supplementary Table S1: “RGB” confusion matrix for plant species classification

RGB		Plant Species Reference Data												Total	Producer Accuracy
		Aster	Bluestem	Boneset	Red Cedar	Dogwood	Goldenrod	Ground	Rattlesnake	Sapling	Sedge	Shadow	Indiangrass		
Map Data	Aster	0	5	1	1	2	2	0	0	1	0	0	3	15	0%
	Bluestem	7	19	6	2	5	13	4	1	8	4	2	13	84	23%
	Boneset	1	6	2	0	0	6	0	0	0	2	0	2	19	11%
	Cedar	1	0	0	1	0	2	0	0	0	0	0	2	6	17%
	Dogwood	0	1	1	2	1	0	0	0	0	1	0	2	8	13%
	Goldenrod	7	9	9	2	5	28	0	1	1	3	5	10	80	35%
	Ground	0	5	0	0	0	1	8	0	0	3	0	1	18	44%
	Rattlesnake	0	1	1	0	0	0	0	0	0	1	0	0	3	0%
	Sapling	0	0	1	1	0	0	0	1	2	1	0	2	8	25%
	Sedge	1	2	0	0	1	4	0	0	1	6	1	1	17	35%
	Shadow	1	0	0	2	0	2	1	0	0	0	2	0	8	25%
	Indiangrass	3	11	3	0	0	5	0	0	1	5	2	8	38	21%
Total		21	59	24	11	14	63	13	3	14	26	12	44		
User Accuracy (%)		0%	32%	8%	9%	7%	44%	62%	0%	14%	23%	17%	18%		
Total Accuracy (%)															25%

Supplementary Table S2: “RGB” confusion matrix for PFT classification (PEF = perennial early flowering, PLF = perennial late flowering)

RGB		PFT Reference Data						Total	Producer Accuracy
		PEF	PLF	C4 Grass	C3 Sedge	Woody	Other		
Map Data	PEF	0	1	1	1	0	0	3	0%
	PLF	1	56	35	5	12	5	114	49%
	C4 Grass	1	37	51	9	16	8	122	42%
	C3 Sedge	0	5	3	6	2	1	17	35%
	Woody	1	5	7	2	7	0	22	32%
	Other	0	4	6	3	2	11	26	42%
	Total	3	108	103	26	39	25	304	
User Accuracy (%)		0%	52%	50%	23%	18%	44%		
Total Accuracy (%)									43%

Supplementary
CHM” confusion
species classification

Table S3: “RGB +
matrix for plant

Supplementary Table S4: “RGB + CHM” confusion matrix for PFT classification (PEF = perennial early flowering, PLF = perennial late flowering)

RGB + CHM		Plant Species Reference Data												Total	Producer Accuracy
		Aster	Bluestem	Boneset	Red Cedar	Dogwood	Goldenrod	Ground	Rattlesnake	Sapling	Sedge	Shadow	Indiangrass		
Map Data	Aster	12	4	0	0	1	2	1	0	1	1	0	3	25	48%
	Bluestem	3	23	1	0	1	19	3	2	3	4	2	14	75	31%
	Boneset	0	0	7	1	2	3	0	0	0	1	1	0	15	47%
	Red Cedar	0	2	1	2	0	1	0	0	0	0	2	0	8	25%
	Dogwood	0	0	0	1	2	1	0	0	0	0	0	0	4	50%
	Goldenrod	3	10	5	5	6	25	0	1	3	6	1	14	79	32%
	Ground	0	2	0	0	0	0	8	0	0	0	0	0	10	80%
	Rattlesnake	0	2	0	0	0	0	0	0	0	0	0	0	2	0%
	Sapling	0	0	3	0	1	1	0	0	2	0	2	2	11	18%
	Sedge	0	4	5	1	0	3	1	0	0	11	1	1	27	41%
	Shadow	0	0	0	1	0	2	0	0	1	0	0	0	4	0%
	Indiangrass	3	12	2	0	1	6	0	0	4	3	3	10	44	23%
Total		21	59	24	11	14	63	13	3	14	26	12	44	304	
User Accuracy (%)		57%	39%	29%	18%	14%	40%	62%	0%	14%	42%	0%	23%		
Total Accuracy (%)															33%

RGB + CHM		PFT Reference Data						Total	Producer Accuracy
		PEF	PLF	C4 Grass	C3 Sedge	Woody	Other		
Map Data	PEF	0	0	2	0	0	0	2	0%
	PLF	1	57	31	8	19	3	119	48%
	C4 Grass	2	34	59	7	9	8	119	50%
	C3 Sedge	0	8	5	11	1	2	27	41%
	Woody	0	7	4	0	8	4	23	35%
	Other	0	2	2	0	2	8	14	57%
	Total	3	106	101	26	37	17	304	
User Accuracy (%)		0%	54%	58%	42%	22%	47%		
Total Accuracy (%)									47%

Supplementary Table S5: “Multispectral” confusion matrix for plant species classification

Multispectral		Plant Species Reference Data												Total	Producer Accuracy
		Aster	Bluestem	Boneset	Red Cedar	Dogwood	Goldenrod	Ground	Rattlesnake	Sapling	Sedge	Shadow	Indiangrass		
Map Data	Aster	3	5	2	1	0	5	0	0	1	0	0	2	19	16%
	Bluestem	4	21	5	3	0	11	3	0	2	6	1	10	66	32%
	Boneset	0	1	2	1	3	1	0	0	0	1	0	0	9	22%
	Red Cedar	0	0	0	0	1	0	0	0	1	0	0	0	2	0%
	Dogwood	0	0	1	1	3	5	0	0	1	1	0	0	12	25%
	Goldenrod	12	17	6	3	5	23	1	1	4	6	6	8	92	25%
	Ground	0	4	0	0	0	0	5	0	1	6	0	4	20	25%
	Rattlesnake	0	1	0	0	0	0	0	0	0	0	0	0	1	0%
	Sapling	0	1	1	1	1	0	0	0	2	2	0	0	8	25%
	Sedge	1	1	1	0	1	3	3	1	0	2	0	1	14	14%
	Shadow	0	3	2	1	0	6	0	0	1	1	9	2	25	36%
	Indiangrass	1	5	4	0	0	9	1	1	1	1	3	17	43	40%
Total		21	59	24	11	14	63	13	3	14	26	19	44	311	
User Accuracy (%)		14%	36%	8%	0%	21%	37%	38%	0%	14%	8%	47%	39%		
Total Accuracy (%)															27%

Supplementary Table S6: “Multispectral” confusion matrix for PFT classification (PEF = perennial early flowering, PLF = perennial late flowering)

Multispectral		PFT Reference Data						Total	Producer Accuracy
		PEF	PLF	C4 Grass	C3 Sedge	Woody	Other		
Map Data	PEF	0	0	1	0	0	0	1	0%
	PLF	1	54	33	7	18	7	120	45%
	C4 Grass	1	34	53	7	6	8	109	49%
	C3 Sedge	1	5	2	2	1	3	14	14%
	Woody	0	7	1	3	11	0	22	50%
	Other	0	8	13	7	3	14	45	31%
	Total	3	108	103	26	39	32	311	
User Accuracy (%)		0%	50%	51%	8%	28%	44%		
Total Accuracy (%)									43%

Supplementary Table S7: “Multispectral + CHM” confusion matrix for plant species classification

Multispectral + CHM		Plant Species Reference Data												Total	Producer Accuracy
		Aster	Bluestem	Boneset	Red Cedar	Dogwood	Goldenrod	Ground	Rattlesnake	Sapling	Sedge	Shadow	Indiangrass		
Map Data	Aster	5	0	0	0	1	0	0	0	1	1	0	2	10	50%
	Bluestem	1	28	3	0	0	12	1	0	5	3	2	11	66	42%
	Boneset	2	1	8	0	0	3	0	0	0	1	2	1	18	44%
	Red Cedar	0	0	0	11	0	0	0	0	0	0	0	0	11	100%
	Dogwood	0	0	0	0	3	3	0	0	0	0	1	0	7	43%
	Goldenrod	7	12	13	0	5	32	0	0	4	2	4	6	85	38%
	Ground	0	2	0	0	0	0	7	0	0	2	0	1	12	58%
	Rattlesnake	0	0	0	0	0	0	0	0	0	1	0	0	1	0%
	Sapling	0	0	0	0	5	5	0	0	3	0	0	0	13	23%
	Sedge	1	5	0	0	0	4	2	2	0	15	0	2	31	48%
	Shadow	1	3	0	0	0	1	0	0	1	0	10	0	16	63%
	Indiangrass	4	8	0	0	0	3	3	1	0	1	0	21	41	51%
Total		21	59	24	11	14	63	13	3	14	26	19	44	311	
User Accuracy (%)		24%	47%	33%	100%	21%	51%	54%	0%	21%	58%	53%	48%		
Total Accuracy (%)															45%

Supplementary Table S8: “Multispectral + CHM” confusion matrix for PFT classification (PEF = perennial early flowering, PLF = perennial late flowering)

Multispectral + CHM		PFT Reference Data						Total	Producer Accuracy
		PEF	PLF	C4 Grass	C3 Sedge	Woody	Other		
Map Data	PEF	0	0	0	1	0	0	1	0%
	PLF	0	70	22	4	11	6	113	62%
	C4 Grass	1	23	68	4	5	6	107	64%
	C3 Sedge	2	5	7	15	0	2	31	48%
	Woody	0	8	0	0	22	1	31	71%
	Other	0	2	6	2	1	17	28	61%
	Total	3	108	103	26	39	32	311	
User Accuracy (%)		0%	65%	66%	58%	56%	53%		
Total Accuracy (%)									61%

Supplementary Table S9: “Multispectral + CHM + Phenology” confusion matrix for plant species classification

Multispectral + CHM + Phenology		Plant Species Reference Data												Total	Producer Accuracy
		Aster	Bluestem	Boneset	Red Cedar	Dogwood	Goldenrod	Ground	Rattlesnake	Sapling	Sedge	Shadow	Indiangrass		
Map Data	Aster	0	0	0	0	1	1	0	0	0	0	0	0	2	0%
	Bluestem	1	11	1	0	0	5	0	0	3	2	0	2	25	44%
	Boneset	1	0	12	0	2	1	0	1	1	1	0	4	23	52%
	Red Cedar	0	0	0	11	0	2	0	0	0	0	0	0	13	85%
	Dogwood	0	0	0	0	4	0	0	0	1	0	0	0	5	80%
	Goldenrod	2	4	5	0	5	38	0	0	4	2	4	7	71	54%
	Ground	0	5	0	0	0	0	8	0	0	1	0	1	15	53%
	Rattlesnake	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
	Sapling	0	0	1	0	1	3	0	0	1	0	0	0	6	17%
	Sedge	0	0	1	0	0	2	3	2	0	15	0	3	26	58%
	Shadow	0	5	0	0	1	7	0	0	1	0	13	0	27	48%
	Indiangrass	1	6	4	0	0	0	2	0	3	5	2	23	46	50%
Total		5	31	24	11	14	59	13	3	14	26	19	40	259	
User Accuracy (%)		0%	35%	50%	100%	29%	64%	62%	0%	7%	58%	68%	58%		
Total Accuracy (%)															52%

Supplementary Table S10: “Multispectral + CHM + Phenology” confusion matrix for PFT classification (PEF = perennial early flowering, PLF = perennial late flowering)

Multispectral + CHM + Phenology		PFT Reference Data						Total	Producer Accuracy
		PEF	PLF	C4 Grass	C3 Sedge	Woody	Other		
Map Data	PEF	0	0	0	0	0	0	0	0%
	PLF	1	60	15	3	13	4	96	63%
	C4 Grass	0	12	42	7	6	4	71	59%
	C3 Sedge	2	3	3	15	0	3	26	58%
	Woody	0	6	0	0	18	0	24	75%
	Other	0	7	11	1	2	21	42	50%
	Total	3	88	71	26	39	32	259	
User Accuracy (%)		0%	68%	59%	58%	46%	66%		
Total Accuracy (%)									60%

Supplementary Table S11: “Hyperspectral” confusion matrix for plant species classification

Hyperspectral		Plant Species Reference Data											Total	Producer Accuracy
		Aster	Bluestem	Boneset	Red Cedar	Dogwood	Goldenrod	Ground	Rattlesnake	Sapling	Sedge	Indiangrass		
Map Data	Aster	7	0	0	0	0	6	0	0	0	1	0	14	50%
	Bluestem	0	50	2	3	0	1	0	0	3	3	12	74	68%
	Boneset	0	2	17	0	0	0	0	0	0	0	0	19	89%
	Red Cedar	0	0	0	8	0	0	0	0	0	0	0	8	100%
	Dogwood	0	0	0	0	13	0	0	0	0	0	0	13	100%
	Goldenrod	13	3	3	0	1	54	0	0	4	7	1	86	63%
	Ground	0	1	0	0	0	0	12	0	0	0	0	13	92%
	Rattlesnake	0	0	0	0	0	0	0	3	0	0	0	3	100%
	Sapling	0	0	2	0	0	0	0	0	7	0	0	9	78%
	Sedge	1	0	0	0	0	0	1	0	0	15	1	18	83%
	Indiangrass	0	3	0	0	0	2	0	0	0	0	30	35	86%
Total		21	59	24	11	14	63	13	3	14	26	44		
User Accuracy (%)		33%	85%	71%	73%	93%	86%	92%	100%	50%	58%	68%		
Total Accuracy (%)														73%

Supplementary Table S12: “Hyperspectral” confusion matrix for PFT classification (PEF = perennial early flowering, PLF = perennial late flowering)

Hyperspectral		PFT Reference Data						Total	Producer Accuracy
		PEF	PLF	C4 Grass	C3 Sedge	Woody	Other		
Map Data	PEF	3	0	0	0	0	0	3	100%
	PLF	0	100	6	8	5	0	119	84%
	C4 Grass	0	5	95	3	6	0	109	87%
	C3 Sedge	0	1	1	15	0	1	18	83%
	Woody	0	2	0	0	28	0	30	93%
	Other	0	0	1	0	0	12	13	92%
Total		3	108	103	26	39	13	292	
User Accuracy (%)		100%	93%	92%	58%	72%	92%		
Total Accuracy (%)									86%

Supplementary Table S13: “Hyperspectral + CHM” confusion matrix for plant species classification

Hyperspectral + CHM		Plant Species Reference Data										Total	Producer Accuracy	
		Aster	Bluestem	Boneset	Red Cedar	Dogwood	Goldenrod	Ground	Rattlesnake	Sapling	Sedge			Indiangrass
Map Data	Aster	10	0	0	0	0	2	0	0	0	0	0	12	83%
	Bluestem	0	55	0	2	2	1	1	0	0	0	12	73	75%
	Boneset	0	1	20	0	0	1	0	0	2	0	0	24	83%
	Red Cedar	0	0	0	8	0	0	0	0	0	0	0	8	100%
	Dogwood	0	0	0	0	9	0	0	0	0	1	0	10	90%
	Goldenrod	9	0	3	0	2	58	0	0	2	8	3	85	68%
	Ground	0	0	0	0	0	0	12	0	0	0	0	12	100%
	Rattlesnake	0	0	0	0	0	0	0	3	0	0	0	3	100%
	Sapling	0	0	0	0	0	0	0	0	10	0	0	10	100%
	Sedge	2	0	0	1	0	1	0	0	0	16	0	20	80%
	Indiangrass	0	3	1	0	1	0	0	0	0	1	29	35	83%
Total		21	59	24	11	14	63	13	3	14	26	44	292	
User Accuracy (%)		48%	93%	83%	73%	64%	92%	92%	100%	71%	62%	66%		
Total Accuracy (%)														78%

Supplementary Table S14: “Hyperspectral + CHM” confusion matrix for PFT classification (PEF = perennial early flowering, PLF = perennial late flowering)

Hyperspectral + CHM		PFT Reference Data						Total	Producer Accuracy
		PEF	PLF	C4 Grass	C3 Sedge	Woody	Other		
Map Data	PEF	3	0	0	0	0	0	3	100%
	PLF	0	103	4	8	6	0	121	85%
	C4 Grass	0	2	99	1	5	1	108	92%
	C3 Sedge	0	3	0	16	1	0	20	80%
	Woody	0	0	0	1	27	0	28	96%
	Other	0	0	0	0	0	12	12	100%
Total		3	108	103	26	39	13	292	
User Accuracy (%)		100%	95%	96%	62%	69%	92%		
Total Accuracy (%)									89%