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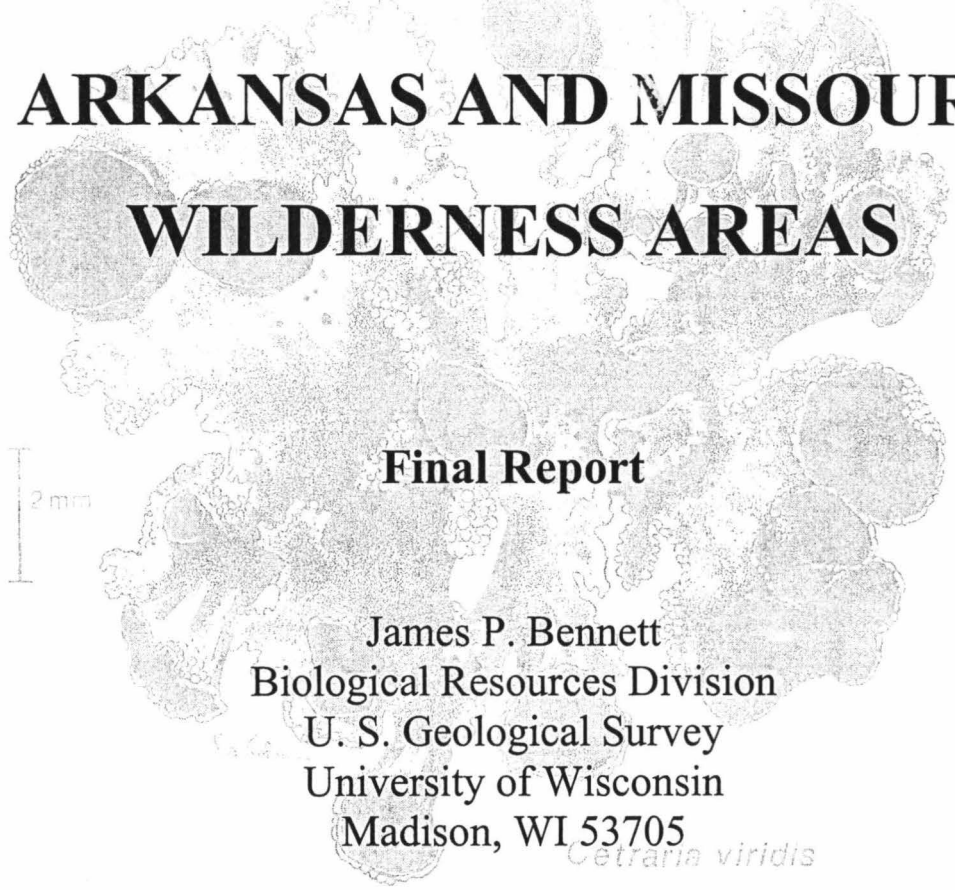

Final Report

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ABSTRACT

In the final report of the first study of the lichens and air quality in the Hercules Glades Wilderness of the Mark Twain National Forest (Wetmore, 1992a) it was recommended that a re-study of the elemental analysis of lichens be done every five years. The present report is on the restudy done in 2000. This report also includes comparison with new collections from Caney Creek Wilderness of the Ouachita National Forest and Upper Buffalo River Wilderness of the Ozark National Forest.

In the present study lichens were collected during May, 2000 at the same localities as the previous studies in Hercules Glades by the second author. The methods used were the same as in the previous studies.

The increases at Hercules Glades appear to be occurring in the eastern part of the wilderness near Hercules Lookout Tower and Long Creek. Nutritional elements have decreased concurrently in the same part of the wilderness compared to the western part.

Elemental analysis values for Caney Creek and Upper Buffalo River were comparable to other areas studied and seem to be in the normal range for clean areas.

It is also recommended that further studies be done in Hercules Glades to discover the causes for the increases in elemental levels since the original study.

ACKNOWLEDGMENTS

The NPS and USFS personnel have been very helpful in assisting with the field work and analysis of the data. The first author did the statistical analysis. The study was made possible by funds from the U. S. Forest Service and the U. S. Geological Survey, Biological Resources Division. The assistance of all of these is gratefully acknowledged.

INTRODUCTION

Lichens are able to accumulate chemical elements in the excess of their metabolic needs depending on the levels in the substrate and air and, since lichens are slow growing and long lived, they serve as good summarizers of the environmental conditions in which they are growing. Chemical analysis of the thallus of lichens growing in areas of high fallout of certain elements will show elevated levels in the thallus. Toxic substances (such as sulfur) are also accumulated and determination of the levels of these toxic elements can provide indications of sub-lethal but elevated levels in the air (Wetmore, 1987).

During 1991 a complete study of lichens and air quality was done in Hercules Glades (Wetmore 1992a), including a species list and elemental analysis of lichens at several localities. The reports showed no elevated accumulation of elements at any locality. The reports recommended that a restudy of elemental analysis be done every five years. During 2000 elemental re-sampling was done at Hercules Glades in conjunction with a floristic air quality study at two other wilderness areas in Arkansas (Caney Creek and Upper Buffalo River, Wetmore 2001).

In this report comparisons are also made with other Federal Areas where the same species have been studied. These areas are Cuyahoga Valley National Recreation Area, Ohio (Wetmore 1986), Delaware Water Gap Recreation Area, New Jersey (Wetmore 1987), Cape Romain National Wildlife Refuge, South Carolina (Wetmore 1989), George Washington Carver National Monument (Wetmore 1992b), Okefenokee National Wildlife Refuge, Georgia (Wetmore 1991a), and St. Croix National Scenic Riverway, Minnesota and Wisconsin (Wetmore 1991b).

METHODS

Methods used in the present study were the same as those of the previous study (Wetmore,

1992a, 1992b). In Hercules Glades all of the previous elemental analysis localities were again sampled in August, 2000. These localities were: Coy Bald, Persimmon Hollow, 2 mi NW of Hercules Tower, Long Creek, and half mile NW of Hercules Tower. In Caney Creek collections were made at W of Buckeye Mt. and SW of Porter Mt. In Upper Buffalo collections were made at Upper Boen Gulf and SE of Turner Ward Knob. GPS readings of latitude and longitude were taken at each site and are given in Appendix II.

One bag of each species was collected at each site, cleaned, ground, and analyzed for chemical constituents. Lichens were cleaned but not washed. Three replicates were obtained from each bag of each species for each locality. Multi element analysis was by ICP and sulfur by infra red absorption by the Soils Analysis Lab, University of Minnesota using the same methods used in the previous study (Wetmore 1992a, 1992b). In the first study two species were analyzed (*Cladina subtenuis*, and *Punctelia rudecta*) in Hercules Glades. In the present study *C. subtenuis* was collected in Hercules Glades where adequate material could be found. *Punctelia rudecta* was the only species found in abundance at Caney Creek and Upper Buffalo for analysis. Biological standards were also included with the unknowns.

Twenty four lichen samples were collected from Hercules Glades in 2000, 9 *Cladina*s and 15 *Punctelia*s. The latter species was also collected at Caney Creek Wilderness (4) and Upper Buffalo River (7). These were analyzed for 16 chemical elements, for a total of 560 data points (see appendix). There were no values below the detection limits of the instruments. The data were merged with the comparable data from the 1991 study, and with chemical data for the same species from other study areas. Two-way analyses of variance were performed on the effects of species, year and their interaction. One-way analyses of variance were performed on the effects of localities within Hercules Glades, the effects of two different Arkansas wilderness areas, and other areas with the same species. *A*

posteriori mean separation tests were performed using Tukey's HSD test. All statistics were computed using *JMP* 4.

RESULTS

1991 and 2000 Comparison

Average and standard errors of element concentrations by species, year and species x year are shown in Table 1. All species comparisons were significantly different statistically at the 0.05 probability level. Concentrations of Al, Cr, Fe, Mg, Mn, and Na were all higher in *Cladina*, while the rest of the other elements were higher in *Punctelia*. Most of the elements that are higher in *Cladina* are found in soils, which should be higher in this ground-dwelling species.

All but Mn and P were significantly different between years, with Al, B, Ca, Cd, Cr, Cu, Fe, Mg, Na, Ni, S and Zn higher in 2000 across both species. Lead was lower across species in 2000, probably due to the lead phase out in gasoline.

Half the elements had significant species by year interactions. These interactions included opposite or non-parallel responses to year by species, and were not consistent among elements. Elements that have increased in both species, but not the same amount include Al, B, Cr, Fe, Na and Zn, all of which are soil elements. This suggests that the samples from 2000 may have had more soil in them than the 1991 samples.

Element Concentrations at Different Localities in Hercules Glades

The concentrations of six elements that were significantly different among the five Hercules Glades collection localities are shown in Table 2. These values are averaged across the two species.

The three localities in the eastern part of the wilderness, Long Creek, and the two localities near Hercules Lookout Tower, have the highest concentrations of Ni, Pb, S and Zn. Magnesium and Mn have the lowest concentrations in the eastern part of the wilderness. These latter elements are nutritional elements and may be lower because of physiological stress from the higher pollutant elements in the east.

Element Concentrations in Hercules Glades Wilderness, Misssouri and Two Arkansas Wilderness Areas in 2000

Punctelia rudecta was sampled at two additional wilderness areas in Arkansas in 2000 and analyzed for the same elements: Caney Creek and Upper Buffalo River. The average element concentrations are shown in Table 3.

Four elements were significantly different between the three areas: B, Cd, K and P. All four were highest at Caney Creek, although Cd there was equal to the concentration at Hercules Glades. Other pollutant elements were highest at Caney Creek, e.g. S, or at Hercules, e.g. Pb, but the differences were not statistically significant with these sample sizes.

Other Areas with the Same Species

The two species sampled at Hercules Glades have been sampled previously at other wildernesses or national parks. Table 4 contains average element concentrations for these two species at these other areas. It is evident that Ca, Mg, Mn and S are significantly higher in *Cladina* at Hercules Glades, while Na is significantly lower than the other two areas. Lead and Zn are in between the other two areas for *Cladina*.

For *Punctelia rudecta*, Al, Ca, Na and Cr are generally higher in Hercules Glades, George Washington Carver and St. Croix compared to Cuyahoga Valley and Delaware Water Gap, while the reverse is true for Pb, S, K, Nn and Zn. This seems to reflect a pattern of higher pollution at Cuyahoga Valley and Delaware Water Gap compared to the three parks farther west.

DISCUSSION AND CONCLUSIONS

In nine years most elements have increased at Hercules Glades, including soil elements and pollutant elements. Lead, however, is an exception: it has decreased in both species, probably due to the overall decrease in lead by the increased use of unleaded gasoline. Manganese and phosphorus have not changed over the nine years at all in either species.

The increases at Hercules Glades appear to be occurring in the eastern part of the wilderness near Hercules Lookout Tower and Long Creek. Nutritional elements have decreased concurrently in the same part of the wilderness compared to the western part. Further sampling and research is needed to discover the causes of these increases as no obvious sources are known.

Although lead was highest at Hercules Glades compared to Caney Creek and Buffalo River, it was not significantly different. Most elements were comparable among the three wilderness areas. Of the four elements that were significantly different among the three wildernesses, Hercules was not the highest or lowest for any of them.

Lead at Hercules Glades was not as high as at other areas where the two species have been studied, but this observation is confounded by the fact that the other areas were sampled in earlier years when lead may have been higher. Some of these areas were sampled over a decade earlier.

For *Cladina*, elements associated with sea salts are lower in Hercules Glades because it is not near the ocean. For *Punctelia*, elements associated with air pollutants are lower in Hercules Glades compared to two eastern parks known to have higher levels of pollutants.

RECOMMENDATIONS

The original recommendation that elemental analyses be restudied every five years is again made here. Continued periodic study will help to determine whether the changes in certain elements are due to random changes or part of a trend with some significance.

Further study should be done in Hercules Glades to understand the elemental gradients and changes in lichen contents.

LITERATURE CITED

Wetmore, C. M. 1986. Lichens and air quality in Cuyahoga Valley National Recreation Area. Final Report submitted to U. S. National Park Service. 31pp.

Wetmore, C. M. 1987. Lichens and air quality in Delaware Water Gap Recreation Area. Final Report submitted to U. S. National Park Service. 31pp.

Wetmore, C. M. 1989. Lichens and air quality on Cape Romain National Wildlife Refuge. Final Report submitted to U. S. Fish and Wildlife Service. 24 pp.

Wetmore, C. M. 1991a. Lichens and air quality in Okefenokee National Wildlife Refuge. Final Report submitted to U. S. Fish and Wildlife Service. 31pp.

Wetmore, C. M. 1991b. Lichens and air quality on St. Croix National Scenic Riverway. Final Report submitted to U. S. National Park Service. 38pp.

Wetmore, C. M. 1992a. Lichens and Air Quality in Hercules Glades of the Mark Twain National Forest. Final Report submitted to U. S. Forest Service. 21pp.

Wetmore, C. M. 1992b. Lichens and air quality in George Washington Carver National

Monument. Final Report submitted to U. S. National Park Service. 14pp.

Wetmore, C. M. 2001. Lichens and Air Quality in Caney Creek and Upper Buffalo River Wilderness Areas. Final Report submitted to USDA Forest Service.

Table 1. Means and standard errors of 16 elements in two lichen species from Hercules Glades in 1991 and 2000. Elements with significant species x year interactions are shown in bold font.

Element	Species	*C. subtenuis*	*P. rudecta*	1991	2000	*C. subtenuis*		*P. rudecta*	
						1991	2000	1991	2000
	Mean	915.8	570.1	362.4	1123.5	**314.5**	**1517.2**	**410.4**	**729.8**
Al	SE	49.23	40.76	43.24	47.07	64.45	74.42	57.65	57.65
	Mean	1.8	2.2	1.1	2.8	**1.2**	**2.4**	**1.0**	**3.3**
B	SE	0.06	0.05	0.06	0.06	0.08	0.1	0.08	0.08
	Mean	904.4	79351.4	45262.8	34993	**793.2**	**1015.6**	**89732.4**	**68970.4**
Ca	SE	3332.1	2759.24	2926.62	3186.1	4362.75	5037.67	3902.16	3902.16
	Mean	0.1	0.4	0.2	0.3	0.1	0.2	0.4	0.5
Cd	SE	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03
	Mean	1.5	1.2	0.8	1.9	**0.5**	**2.4**	**1.0**	**1.4**
Cr	SE	0.09	0.07	0.08	0.08	0.11	0.13	0.1	0.1
	Mean	3.3	5.1	2.4	6.0	1.7	4.9	3.1	7.1
Cu	SE	0.24	0.2	0.21	0.23	0.32	0.36	0.28	0.28
	Mean	669.3	378	226.3	821	**209.3**	**1129.4**	**243.3**	**512.7**
Fe	SE	39.84	32.99	34.99	38.09	52.16	60.23	46.65	46.65
	Mean	1380.9	1769.5	1692.5	1457.9	1507.3	1254.5	1877.6	1661.3
K	SE	43.63	36.13	38.32	41.72	57.12	65.96	51.09	51.09
	Mean	427.9	330.5	324.9	433.5	345.3	510.6	304.5	356.5
Mg	SE	15.59	12.91	13.69	14.9	20.41	23.56	18.25	18.25
	Mean	103.1	49.6	73.9	78.8	95.1	111.1	52.7	46.5
Mn	SE	8.75	7.25	7.69	8.37	11.46	13.23	10.25	10.25
	Mean	39.3	30.3	26	43.6	**33.6**	**45**	**18.4**	**42.3**
Na	SE	1.82	1.51	1.6	1.74	2.39	2.76	2.14	2.14
	Mean	1.2	1.6	1	1.7	**0.5**	**1.9**	**1.5**	**1.6**
Ni	SE	0.08	0.07	0.07	0.08	0.11	0.12	0.1	0.1
	Mean	379.4	496.6	426.3	449.7	366	392.9	486.6	506.5
P	SE	17.66	14.62	15.51	16.88	23.12	26.69	20.68	20.68
	Mean	3.1	9.8	7.1	5.8	**2.6**	**3.5**	**11.7**	**8.0**
Pb	SE	0.47	0.39	0.41	0.45	0.61	0.7	0.55	0.55
	Mean	698.3	1070.5	742.2	1026.6	567.1	829.4	917.3	1223.7
S	SE	32.31	26.76	28.38	30.9	42.31	48.85	37.84	37.84
	Mean	13.2	21.7	14.2	20.7	**11.7**	**14.7**	**16.8**	**26.6**
Zn	SE	0.7	0.58	0.62	0.67	0.92	1.06	0.82	0.82
Number of samples		21	30	27	24	12	9	15	15

Table 2. Element concentrations at five localities in Hercules Glades in 2000, averaged across two lichen species. Localities are arranged roughly in west to east order. Means in rows followed by different letters (a,b,c) are significantly different using the Tukey HSD test. The F value and its' probability from a one-way analysis of variance are found in the last two columns.

Element	Persimmon Hollow	Coy Bald	Long Creek	2 miles from Herc. Tower	0.5 mile from Herc. Tower	F	F prob
Mg	407.72a	377.66ab	393.84ab	306.24ab	291.56b	3.21	0.02
Mn	67.37b	132.97a	52.88b	39.84b	34.25b	18.29	0.00
Ni	1.15b	1.17b	1.9a	1.59ab	1.32ab	3.24	0.02
Pb	5.22b	5.73b	8.32ab	10.32a	8.23ab	2.56	0.05
S	719.33b	820.42ab	1082.78a	1075a	1061.67a	5.51	0.00
Zn	14.79b	16.97ab	23.76a	19.2ab	18.84ab	3.24	0.02
Number of samples	15	12	9	6	9		

Table 3. Element concentrations in *Punctelia rudecta* from three wilderness areas in Arkansas, summer, 2000. Elements that are significantly different are in bold print. Means in rows followed by different letters (a,b,c) are significantly different using the Tukey HSD test. The F value and its' probability for the area affect are given in columns 5 and 6, and the same for the nested locality effect in the last two columns.

Element	Buffalo River	Caney Creek	Hercules Glades	F Area	Probability	F Locality	Probability
Al	519.88	711.77	729.79	1.11	0.380	11.67	0.000
B	**3.8ab**	**4.45a**	**3.31b**	**8.06**	0.015	3.32	0.022
Ca	112241	77237	68970	3.84	0.075	10.29	0.000
Cd	**1.14a**	**0.45ab**	**0.46b**	**5.28**	0.040	18.1	0.000
Cr	1.19	1.44	1.44	2.15	0.180	7.71	0.000
Cu	5.72	6.6	7.06	1.03	0.400	2.91	0.036
Fe	350.53	521.52	512.65	1.17	0.370	12.34	0.000
K	**1463.46b**	**2864.15a**	**1661.31b**	**7.51**	0.018	11.89	0.000
Mg	459.96	498.1	356.52	3.13	0.107	11.07	0.000
Mn	90.37	96.71	46.52	0.63	0.560	15.68	0.000
Na	38.66	71.57	42.25	2.49	0.153	34.95	0.000
Ni	2.13	1.74	1.61	1.49	0.290	2.05	0.110
P	**377.37b**	**1155.17a**	**506.52b**	**8.69**	0.013	24.11	0.000
Pb	7.17	5.8	8.02	1.58	0.270	4.9	0.004
S	727.14	1457.5	1223.67	3.5	0.089	17.61	0.000
Zn	24.52	23.8	26.6	0.51	0.620	2.34	0.075
Number of samples	7	4	15				

Table 4. Element concentrations in two lichen species at other study areas compared to Hercules Glades. Elements that are significantly different between areas are shown in bold font. Means in rows within species followed by different letters (a,b,c) are significantly different using the Tukey HSD test. The F value and its' probability from a one-way analysis of variance are found in the last two columns of each species section.

Element	*Cladina subtenuis*					*Punctelia rudecta*						
	Cape Romain	**Hercules Glades**	**Okefenokee**	**F**	**Probability**	**Cuyahoga Valley**	**Delaware Water Gap**	**George Washington Carver**	**Hercules Glades**	**St. Croix**	**F**	**Probability**
Al	351.5	918.2	239	1.78	0.230	**245bc**	**210b**	**729ac**	**570a**	**773a**	14.60	0.000
B	2.4	1.78	1.47	0.88	0.450	2.8	1.1	1.8	2.2	2.3	2.84	0.042
Ca	**318.5ab**	**886.4a**	**192.3b**	9.49	0.008	**20695bc**	**33938b**	**81356a**	**79351ac**	**87717a**	8.11	0.000
Cd	0.2	0.14		1.62	0.260	**0.45a**	**1.4a**	**0.5a**	**0.41b**	**0.71a**	3.10	0.030
Cr	0.6	1.49	0.43	1.66	0.250	**1.05ab**	**0.43b**	**1.46a**	**1.23a**	**1.23a**	12.62	0.000
Cu	2.25	3.29	0.97	2.24	0.170	**4.4ab**	**3.32b**	**7.3a**	**5.07ab**	**3.84b**	4.02	0.010
Fe	374.5	669.6	121.7	1.63	0.260	**330a**	**270b**	**536a**	**378a**	**570a**	3.58	0.017
K	1261.5	1383.7	1069	2.33	0.160	**3486a**	**3151a**	**2902a**	**1769b**	**2696a**	10.23	0.000
Mg	**292.5ab**	**425a**	**179.7b**	5.23	0.035	**473a**	**348b**	**639a**	**331b**	**711a**	9.67	0.000
Mn	**10.6b**	**106.7a**	**9.33b**	15.80	0.002	**47.9a**	**109.3a**	**25.1a**	**49.6b**	**29.6b**	4.87	0.004
Na	**146.3a**	**40.5b**	**161a**	14.20	0.002	**13.45bc**	**11c**	**67.2a**	**30.3b**	**27.3b**	10.02	0.000
Ni	1.45	1.21	0.93	0.36	0.710	**1.15b**	**1.72b**	**3.41a**	**1.56b**	**1.43b**	6.46	0.001
P	482.5	384.9	436	1.78	0.230	1174	882	985	497	893	2.95	0.036
Pb	**5.5a**	**2.98ab**	**2.1b**	5.00	0.039	**33a**	**28.7a**	**12a**	**9.8b**	**17.3a**	3.73	0.014
S	**625.5ab**	**708.3a**	**393.3b**	5.93	0.026	**1873a**	**1492a**	**1260a**	**1071b**	**1046b**	7.12	0.001
Zn	**18.5a**	**13.3ab**	**9.7b**	8.53	0.010	**39.9a**	**132.8a**	**30.1b**	**21.7b**	**32.5b**	10.33	0.000
Number of samples	2	6	3			2	11	5	10	10		
Year sampled	1988	1991 & 2000	1989			1985	1986	1991 & 2000	1991 & 2000	1988		

Appendix I

Chemical element data for two lichen species at three Arkansas wilderness areas for 2000. All element concentrations are in parts per million.

Area	Locality	Species	Al	B	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	P	Pb	S	Zn
Hercules Glades	Coy Bald	C. subtenuis	1052.78	1.72	651.75	0.12	1.37	5.58	755.4	993.88	383.02	108.89	43.43	1.18	309.56	2.88	855	12.74
Hercules Glades	Coy Bald	C. subtenuis	1093.04	1.9	667.08	0.14	1.96	4.62	788.18	1033.94	404.08	119.5	41.08	1.42	333.46	3.16	770	13.14
Hercules Glades	Coy Bald	C. subtenuis	1121.62	2.16	657.74	0.16	1.44	5.58	796.22	1110.0	422.78	136.52	40.94	1.24	347.04	3.32	770	13.92
Hercules Glades	Persimmon Holl.	C. subtenuis	1928.64	2.6	1519.3	0.18	2.68	5.38	1533.56	1244.8	591.82	101.06	52.0	2.2	404.02	3.88	850	12.36
Hercules Glades	Persimmon Holl.	C. subtenuis	2315.6	2.8	1625.9	0.24	3.26	6.16	1851.9	1304.7	635.16	117.28	53.14	2.52	429.02	4.92	750	13.32
Hercules Glades	Persimmon Holl.	C. subtenuis	1379.1	2.28	1253.54	0.16	2.22	6.6	1086.68	1490.48	527.2	77.36	53.44	1.66	446.82	3.2	870	12.38
Hercules Glades	Long Creek	C. subtenuis	1631.82	2.7	861.98	0.18	3.9	4.24	1120.3	1384.58	530.6	106.14	43.72	2.74	414.42	3.12	800	18.64
Hercules Glades	Long Creek	C. subtenuis	1676.22	2.7	898.9	0.2	2.6	2.86	1202.28	1404.04	546.12	117.84	39.88	2.04	450.24	3.74	920	18.8
Hercules Glades	Long Creek	C. subtenuis	1455.6	2.38	1004.64	0.18	2.44	2.7	1029.86	1324.4	554.38	115.3	37.62	1.86	401.18	3.18	880	17.42
Hercules Glades	Coy Bald	P. rudecta	440.16	3.28	63510	0.56	1.25	7.85	306.21	1934.68	404.58	143.26	54.73	1.47	595.41	5.68	1080	28.84
Hercules Glades	Coy Bald	P. rudecta	378.78	3.1	60002	0.58	1.18	6.42	260.46	1874.26	368.24	135.92	68.6	1.44	588.42	5.38	1120	29.76
Hercules Glades	Coy Bald	P. rudecta	477.78	3.3	78180	0.6	1.26	6.54	333.28	1809.28	378.64	136.9	55.76	1.58	581.0	6.24	1150	24.9
Hercules Glades	Persimmon Holl.	P. rudecta	629.16	2.9	68100	0.32	1.34	6.92	419.82	1718.58	355.4	17.54	34.64	1.48	479.38	5.7	800	21.6
Hercules Glades	Persimmon Holl.	P. rudecta	612.56	3.6	99106	0.4	1.28	7.76	418.14	1426.1	300.22	20.14	31.32	1.52	429.48	7.68	1030	20.98
Hercules Glades	Persimmon Holl.	P. rudecta	649.64	3.06	65614	0.34	1.34	8.72	444.26	1671.42	349.7	20.42	32.3	1.52	463.82	6.44	1020	23.82
Hercules Glades	2 mi NW Herc. Tower	P. rudecta	1145.52	3.16	62934	0.48	1.72	6.32	843.54	1282.44	314.82	22.24	48.3	1.8	405.64	9.3	1150	20.7
Hercules Glades	2 mi NW Herc. Tower	P. rudecta	873.62	3.46	68446	0.44	1.56	6.74	616.66	1459.52	280.42	22	46.14	1.7	413.4	8.14	1330	25.48
Hercules Glades	2 mi NW Herc. Tower	P. rudecta	1124.98	3.58	64386	0.5	1.86	7.72	798.46	1519.58	333.5	24.18	57.34	1.94	449.66	11.74	1330	27.38
Hercules Glades	Long Creek	P. rudecta	567.58	3.26	67548	0.44	1.48	10.92	402.46	1962.14	366.34	30.16	33.82	1.56	557.06	8.2	1570	29.1
Hercules Glades	Long Creek	P. rudecta	756.67	3.93	98840	0.48	1.51	8.7	535.74	1555.41	319.04	34.01	34.83	1.72	521.64	9.16	1235	27.79
Hercules Glades	Long Creek	P. rudecta	743.8	3.94	94688	0.48	1.7	6.46	531.9	1836.58	354.44	33.86	35.1	1.9	636.48	8.9	1390	33.42
Hercules Glades	0.5 mi NW Herc. Tower	P. rudecta	818.2	2.92	48178	0.44	1.4	5.22	579.2	1866.48	410.16	19.66	36.8	1.54	611.94	8.9	1360	33.42
Hercules Glades	0.5 mi NW Herc. Tower	P. rudecta	876.06	3.02	42388	0.46	1.36	4.82	614.44	1583.24	406.7	19.38	33.18	1.5	452.62	9.92	1430	26.62
Hercules Glades	0.5 mi NW Herc. Tower	P. rudecta	852.26	3.08	52636	0.44	1.4	4.8	585.2	1419.88	405.52	18.08	30.94	1.5	411.78	8.92	1360	25.18
Caney Creek	W of Buckeye Mt.	P. rudecta	840.6	4.56	37160	0.46	1.46	6.42	623.88	3546.2	583.6	132.86	100.06	1.74	1297.48	5.18	1770	27.42
Caney Creek	W of Buckeye Mt.	P. rudecta	1031.4	5.00	42084	0.5	1.74	7.32	766.14	3499.4	611.78	181.16	97.38	2.0	1427.18	6.8	1890	29.44
Caney Creek	SW of Porter Mt.	P. rudecta	520.88	4.12	110532	0.42	1.26	6.36	369.66	2294	416.44	39.2	47.1	1.6	972.88	5.62	1060	19.82
Caney Creek	SW of Porter Mt.	P. rudecta	454.18	4.1	119172	0.4	1.28	6.3	326.4	2117	380.56	33.62	41.72	1.6	923.14	5.6	1110	18.5
Upper Buffalo	SW of Porter Mt.	P. rudecta	512.08	4.44	127568	0.48	1.24	6.48	376.32	1892.6	357.38	32.54	40.72	1.66	826.08	5.84	1120	19.06
Upper Buffalo	Upper Boen Gulf	P. rudecta	673.89	3.82	103210	1.12	1.24	5.38	450.17	1218.32	505.31	165.47	34.3	2.68	330.33	6.31	670	36.44
Upper Buffalo	Upper Boen Gulf	P. rudecta	643.42	3.98	105712	1.2	1.36	5.32	432.5	1207.4	541.42	143.62	34.46	3.08	295.02	6.14	730	37.02
Upper Buffalo	Upper Boen Gulf	P. rudecta	727.58	3.9	105522	1.12	1.28	5.52	479.28	1213.54	514.78	100.7	34.84	2.64	311.32	6.28	560	35.54
Upper Buffalo	Upper Boen Gulf	P. rudecta	378.2	3.46	115198	1.42	1.08	5.8	249.62	1597.78	436.42	62.86	43.4	1.64	299.88	8.7	590	15.24
Upper Buffalo	SE of Turner Ward Knob	P. rudecta	336.7	3.5	108326	1.28	1.04	5.6	225.3	1653.44	464.42	65.46	43.88	1.6	298.18	8.28	710	14.4
Upper Buffalo	SE of Turner Ward Knob	P. rudecta	367.27	3.48	120149	1.35	1.06	5.95	240.51	1461.16	399.97	61.97	39.0	1.64	280.76	8.62	710	13.93

Appendix II

ELEMENTAL ANALYSIS LOCALITIES

The following latitudes and longitudes were obtained during the 2000 survey by GPS. Locality names in bold are those used in the tables.

Hercules Glades elemental analysis localities

Taney County, Missouri, Mark Twain National Forest, Hercules Glades Wilderness

1. **2 miles NW of Hercules** Lookout **Tower**. In open glade with limestone and scattered grass and juniper and oaks. Sec. 11, T23N, R18W. 36° 41'53"N 92° 54'33"W.

2. 0.5 miles north of **Persimmon Hollow**. On saddle ridge west of trail with open areas, hickory, oaks, and juniper. Sec. 20, T23N, R18W. 36° 39'34"N 92° 57'09"W.

3. Along trail south of **Long Creek**. On ridge and northwest slope in openings, junipers and oaks. Sec.14, T23N, R18W. 36° 40'31"N 92° 54'38"W.

4. **0.5 miles northwest of Hercules** Lookout **Tower**. On ridge and northeast slope with hickory, oaks, and juniper. Sec. 12, T23N, R18W. 36° 41'26"N 92° 53'15"W.

5. 0.5 miles northeast of **Coy Bald**. On plateau near small rock piles among oaks, hickory, and juniper with small openings. Sec. 9, T23N, R18W. 36° 41'22"N 92° 56'46"W.

Caney Creek elemental analysis localities

Polk County, Arkansas. Ouachita National Forest. Caney Creek Wilderness

1. Half mile **W of Buckeye Mt.** On ridge with hickory, oaks and rock cliffs, elev. 2160 ft. Sec. 13, T4S, R29W. 34° 24'16"N, 94° 02'37"W. 20 May 2000.

2. SW corner of wilderness **SW of Porter Mt.** On western point of ridge just inside border with elm, oaks, hickory, short leaf pines, and black cherry, elev. 1420 ft. Sec. 24, T4S, R30W. 34° 23'30"N, 94° 09'35"W. 24 May 2000.

Upper Buffalo River elemental analysis localities

Newton County, Arkansas, Ozark National Forest, Upper Buffalo River Wilderness Area

1. **Upper Boen Gulf** Branch, S of Mossville. Stream valley with oak, hickory, beech, and red maple, elev. 2000 ft. Sec. 11, T14N, R23W. 35° 53'04"N, 93° 23'17"W. 28 May 2000.

2. Half mile **SE of Turner Ward Knob**. On N facing hill above ravine with oaks, hickory, and red maple, elev. 2150 ft. Sec. 20, T14N, R23W. 35° 51'24"N, 93° 26'39"W. 31 May 2000.