

Working

2004 Lichen Studies in the Rainbow Lake Wilderness of the Chequamegon National Forest, Wisconsin

Final Report

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Summary

In May and June 2004, collections were made for elemental analysis at the three localities used in the original study (Wetmore 1993). Many of the original collection localities were revisited to take latitude and longitude readings. In addition, collections were made at 11 new localities in the wilderness.

Ten new species records for the wilderness were found during this study.

One rare lichen, *Caloplaca parvula*, was found just outside of the wilderness near the Perch Lake Campground. This species is on the Region 9 Forester's Sensitive Species list.

Statistical analyses of the elemental data from the 2004 samples revealed significant decreases in Pb, a pattern of elevated concentrations at the North Country Trail locality in the northwest part of the Wilderness, and differences between changes at the Wilderness and the nearby St. Croix National Scenic Riverway.

It is recommended that additional black ash bogs be investigated within the wilderness to attempt to find other occurrences of *Caloplaca parvula* or other rare species.

We recommend that sampling should be done in about five years to determine if Pb decreases more or stays level; if the North Country Trail locality continues to show elevated levels; and to test hypotheses about differences between Rainbow Lake Wilderness and St. Croix National Scenic River.

Introduction

In the final report of the first study of the lichens and air quality in the Rainbow Lake Wilderness Area (Wetmore 1993) it was recommended that a restudy of the elemental analysis of lichens be done every five years. This is a report of the results of a restudy done 12 years later in 2004.

Methods

Field work was done during May and June 2004. Collections were made at the three original elemental analysis localities sampled in the first study. In addition, collections of lichens were made at 11 new localities to attempt to add to the lichen flora.

Many of the localities in the first study were revisited and GPS readings of latitude and longitude were obtained using a Garmin Map 76 GPS with WGS84 Map Datum.

Methods follow those used during the original study in 1992. A complete list of the new collection localities is given in Appendix 1. Collection localities were selected to include additional vegetation types and more representatives of previously sampled types. At each locality voucher specimens of all species found were collected to record the total flora for each locality and to avoid missing different species that might appear similar in the field. At the elemental analysis localities samples of three species were collected: *Evernia mesomorpha* (EVME), *Hypogymnia physodes* (HYPH) and *Parmelia sulcata* (PASU).

Identifications were carried out at the University of Minnesota with the aid of comparison material in the herbarium and using thin layer chromatography for identification of the lichen substances where necessary. The original packet of each collection was deposited in the University of Minnesota Herbarium and the label data was entered into the herbarium computer database.

Elemental analysis methods were the same as used previously using ICP-OES for most elements and infrared absorption for sulfur.

Differences between years for each element were analyzed by unpaired t tests. Differences between localities were tested with a nested analysis of variance. All statistics were performed using *Systat* version 11.

Lichen Flora Results

During the study 314 new lichen collections were made at 11 new localities in the wilderness (one visited twice) and one locality outside. These new localities are listed in Appendix 1. These localities were selected to be in vegetation types not or rarely studied in the original study.

The vegetation map provided by the National Forest staff indicated that there was a white cedar (*Thuja*) stand at locality 2 (Appendix 1). However, only black spruce and tamarack were found and no *Thuja*. Another stand at locality 10 (Appendix 1) that was indicated as red pine was actually a hardwood stand. The vegetation map was probably prepared from an air photo that is very poor and may account for the errors in vegetation types.

During the 2004 study the following ten new species records were found for the wilderness bringing the new total to 205 (Appendix 3).

Amandinea dakotensis
Amandinea punctata
Aspicilia caesiocinerea
Calicium abietinum
Dimerella pineti
Lecanora piniperda
Micarea misella
Ochrolechia androgyna
Peltigera canina
Punctelia hypoleucites

In addition one new species record outside of the wilderness was found (*Caloplaca parvula*) at locality 8 (Appendix 1). This species is on both the Regional Forester's Sensitive Species List for the Upper Great Lakes Forests and on the Minnesota list of threatened or endangered lichens.

Latitude and longitude readings were made at 15 of the localities in the first study, including the elemental analysis localities, with a Garmin Map76 GPS using the WGS85 map datum. Appendix 2 lists all of the 1992 localities with the latitude and longitude added. These data are also given for the new localities in Appendix 1.

A revised species list for the wilderness is in Appendix 3. This is an update of nomenclature of the original species list with the addition of the new records.

Elemental Analysis Results

The number of lichens sampled in both years by locality is shown in Table 1. Four species of lichens were sampled for elemental analyses in 1992, but only three of them were sampled in 2004, because *Cladonia rangiferina* (CLRA) was not found in sufficient abundance in 2004. This is a ground-dwelling lichen that prefers open areas, which are not frequent in the Rainbow Lake Wilderness.

Table 1. Number of lichen samples by year, locality and species at Rainbow Lake Wilderness.*

Locality	Species	1992	2004	Grand Total
Clay Lake	EVME	3	3	6
	HYPH	3	2	5
	PASU	3	2	5
Clay Lake Total		9	7	16
Lee Lake	CLRA	3		3
	EVME	3	3	6
	HYPH	3	3	6
	PASU	3	3	6
Lee Lake Total		12	9	21
N. Country Trail	EVME	3	3	6
	HYPH	3	4	7
	PASU	3	4	7
N. Country Trail Total		9	11	20
Grand Total		30	27	57

*Species codes are explained in the text.

These 57 samples were analyzed for 16 elements for a total of 912 data elements. No measurements were below detection limits and no outliers were detected requiring deletion.

The elemental means for the two sampling years are shown in Table 2, based on the three species sampled in both years. These means were analyzed using a nested analysis variance model, with year as the main factor, and localities nested within years, across species.

Table 2. Element means (ppm) for 1992 and 2004 for three lichen species at Rainbow Lake Wilderness.*

Element	1992	2004	% change, 1992- 2004	Probability
Al	601.1	457.9	-23.8	0.036
B	3.42	4.05	18.4	0.575
Ca	6937	10791	55.6	0.014
Cd	0.398	0.489	22.9	0.059
Cr	1.18	1.14	-3.4	0.710
Cu	4.84	4.42	-8.7	0.414
Fe	657.1	508.4	-22.6	0.047
K	2968	2420	-18.5	0.071
Mg	548.5	562.9	2.6	0.805
Mn	200.0	238.8	19.4	0.474
Na	28.6	24.6	-14.0	0.050
Ni	1.098	1.381	25.8	0.079
P	901.6	756.3	-16.1	0.182
Pb	11.37	5.22	-54.1	0.002
S	1058	1091	3.1	0.817
Zn	68.6	63.8	-7.0	0.249

*Means are averaged across three species and localities; sample size is 27 for each mean. Significantly different means at the 0.05 probability level as determined by unpaired t tests are in bold font.

Six of the 16 elements changed significantly (at the 0.06 probability level) over the 12 year period between samplings. Aluminum, iron, sodium and lead all decreased 14 – 54%, while calcium and cadmium increased 23 - 56%. Lead decreased the most at 54%, while sodium decreased the least at 14%. Nickel increased 26% with a probability of the effect being due to chance of 0.08. Other elements changed comparable amounts but were not significantly different due to the effects of species or locality differences.

Four elements were significantly different between the three localities (Table 3). Boron and sulfur are significantly higher by 12 – 19% at the North Country Trail locality compared to Clay Lake. Iron and nickel are significantly different between localities but the effect is inconsistent between years. Both elements appeared to be higher at North Country Trail in 1992, but increased at the two southern lake localities in 2004. Other elements that are higher at the North Country Trail locality both years include potassium, magnesium, manganese, phosphorus and lead, although these were not statistically significant.

Table 3. Element by locality means (ppm) for 1992 and 2004 for three lichen species at Rainbow Lake Wilderness.*

Element	1992			2004			Probability
	NC Trail	Lee L	Clay L	NC Trail	Lee L	Clay L	
Al	660.24	550.31	592.65	416.12	460.68	520.16	0.139
B	3.95	3.55	2.77	5.05	3.82	2.77	0.012
Ca	7392.58	6993.86	6425.89	11368.02	11622.41	8816.50	0.983
Cd	0.40	0.35	0.44	0.46	0.54	0.47	0.820
Cr	1.28	1.11	1.15	1.07	1.17	1.22	0.208
Cu	5.44	4.56	4.51	4.41	4.00	4.99	0.414
Fe	736.81	591.23	643.31	464.90	532.61	545.69	0.054
K	3284.18	2792.19	2827.29	2713.77	2308.87	2102.04	0.069
Mg	566.17	515.13	564.08	590.98	574.49	503.95	0.779
Mn	228.46	151.54	219.89	288.98	218.98	185.55	0.293
Na	29.61	28.46	27.83	22.97	27.15	24.02	0.205
Ni	1.20	1.09	1.00	1.24	1.59	1.34	0.049
P	1008.87	891.73	804.24	886.07	724.42	593.30	0.258
Pb	12.94	11.01	10.15	5.66	5.09	4.69	0.482
S	1140.00	1014.00	1020.00	1200.00	1024.44	1006.43	<0.001
Zn	67.64	73.62	64.68	60.58	67.40	64.29	0.887
Sample size	9	9	9	11	9	7	

*Means are averaged across three species. Significantly different means at the 0.05 probability level are in bold font. The significance was determined with a nested analysis of variance, with locality nested within year. Means in bold font indicate that all three localities are significantly different within each year.

All but two elements (sodium and sulfur) were significantly different between species (see table of means in Appendix 4). The element differences were consistent across the study area and were considered not to be of importance in interpreting year and locality differences. Although the differences between species were great, *Evernia* increased an average of 15% across all elements, while *Hypogymnia* and *Parmelia* decreased three and six percent, respectively (Table 4). Most changes in elements are comparable among the three species, although Ca, Cd, Mn and maybe Zn varied quite a bit.

Table 4. Percent changes in element concentrations for three species across all localities, 1992-2004.

Element	% change 1992-2004		
	EVME	HYPH	PASU
Al	-19	-36	-19
B	7	27	19
Ca	136	57	22
Cd	98	15	-8
Cr	10	-14	-6
Cu	-15	-14	0
Fe	-17	-33	-18
K	-9	-19	-23
Mg	11	1	0
Mn	99	23	1
Na	-11	-18	-13
Ni	27	38	15
P	8	-17	-25
Pb	-64	-52	-51
S	-1	8	3
Zn	-25	-5	0
Average	15	-3	-6

Discussion

The most significant change in an element over time at Rainbow Lake is the 54% decrease in lead, which is comparable to the 28% decrease seen at St. Croix NSR. The phaseout of lead in gasoline in the U. S. began in 1976 and the primary phaseout was completed in 1986. Levels in lichens in Rainbow Lake in 1992 ranged from 6 to 14 ppm depending on species (Appendix 1) and had decreased to 2 to 7 ppm by 2004, a remarkable decrease for 12 years. The decrease was consistently between 53 to 56% at the three localities, suggesting it was uniform across the wilderness and that Pb reaches the wilderness from a long distance source. Interestingly, Pb decreased about 12% more in *Evernia* than it did in the other two foliose species.

The increase in Ca is unexplained but might be due to improved recovery of the element by the laboratory. The greatest increase was in *Evernia*, followed by *Hypogymnia* and *Parmelia*.

The increase in Cd, while significant statistically, may not be significant biologically because the concentrations are still below one ppm. This may also be due to greater recovery by the laboratory or to increased exposure to automobile emissions because Cd is a constituent of exhaust and brake wear.

Elements that are unchanged over the 12 year time span include nutritional elements (K, Mg, P and possibly Zn), some heavy metals (Cr, Cu and Zn), and B, Mn and S. These elements occurred in these lichens at normal levels and do not appear elevated. The absence of any significant reduction in S is unexplained. There have been reductions in S emissions from electrical generating stations in the Midwest, but there have also been increases in automobile traffic, and automobiles emit S compounds.

None of the absolute elemental concentrations in the three species are at levels that would be considered harmful to the lichens themselves. Relatively elevated levels of some elements, however, may indicate potential problems in other biota or the ecosystem.

The North Country Trail site appears to have elevated levels of some elements compared to the other localities. This could be due to more trail use by visitors or greater proximity to traffic emissions from automobiles on the perimeter road to the west. This can't be proven at this time with this data, however, and more studies would be needed.

The changes in Al, B, K, Pb and S at Rainbow Lake are very similar to the changes at St. Croix NSR which was studied for almost the same time period (Wetmore & Bennett 2004), lending support to some interpretations at both. Al, Fe and Pb have decreased at both areas because of decreases in dust in the northern Great Lakes region and the decline in the use of leaded gasoline. Sulfur, however, decreased at St. Croix NSR but not at Rainbow Lake. S levels at St. Croix NSR were higher over a decade ago and have decreased to less than 900 ppm, while those at Rainbow Lake have remained a little over 1000 ppm. Potassium has remained relatively constant at both areas, but this may be an indication of healthy lichens rather than an environmental effect. Other elements have changed at St. Croix NSR differently than at Rainbow Lake but may be due more to species differences. For example, Mn, Zn and B are much higher at Rainbow Lake but Cd is much higher at St. Croix.

The time span between the two samplings at Rainbow Lake Wilderness is 12 years. At Saint Croix National Scenic Riverway, the lichen *Punctelia rudecta* was sampled twice over a

span of 15 years in 1988 and 2003. Although this species is different from the three species studied at Rainbow Lake, sample sites occur in both studies in Bayfield County, so the studies are useful for comparisons.

Conclusions and Recommendations

Air pollution from leaded gasoline that used to reach the Rainbow Lake Wilderness has declined significantly to the point where further decreases may take longer to occur. Concentrations in lichens in 2004 are below 7 ppm after a 12-year interval. We recommend sampling for this element again in about five years.

Sulfur in lichens at Rainbow Lake has not decreased although it has at St. Croix National Scenic Riverway. Although sulfur levels are comparable in the two areas, difference may be due to species uptake and/or real environmental differences in exposure. A study of the three elemental analysis species at the two areas would provide data to test this hypothesis. This should be done sometime in the next five years.

If the locality on the North Country Trail in the northwest quadrant of the Wilderness is indicative of an exposure problem from local sources, this should be studied soon to gather more data to study it in more detail. We would recommend such a study sometime in the next five years. Meanwhile, the Wilderness staff may want to consider gathering visitation data for different parts of the Wilderness to determine geographic usage patterns.

More black ash bogs within the wilderness should be investigated for the presence of rare lichens, including *Caloplaca parvula*.

Literature Cited

- Wetmore, C. 1993. Lichens and Air Quality in Chequamegon National Forest Rainbow Lake Wilderness Area. Final Report. 25 pp.
- Wetmore, C. M. & Bennett, J. P. 2004. 2003 Lichen Studies in St. Croix National Scenic Riverway. Final Report. 37 pp.

Appendix 1

2004 Rainbow Lake Collection Localities

Total lichens collections were made in these additional localities during the 2004 lichen study. Only one locality (# 8) was outside of the wilderness. The numbers at the end of each locality are the collection numbers of C. Wetmore and the vouchers are deposited in the University of Minnesota Herbarium.

Loc. 1.: Wisconsin, Bayfield Co., Chequamegon National Forest, Rainbow Lake Wilderness. SE side of Beaver Lake. Hemlock and maple forest, elev. 1500 ft. Sec. 32, T46N, R7W. 46°25'03"N, 91°16'03"W. 29 May 2004. #90441-90464.

Loc. 2.: Wisconsin, Bayfield Co., Chequamegon National Forest, Rainbow Lake Wilderness. SE corner of wilderness SE of Wishbone Lake. Black spruce-tamarack bog, elev. 1280 ft. Sec. 8, T46N, R7W. 46°23'20"N, 91°16'13"W. 30 May 2004. #90465-90490.

Loc. 3.: Wisconsin, Bayfield Co., Chequamegon National Forest, Rainbow Lake Wilderness. W side of wilderness W of Bear Pond. Red and sugar maple, red oak, and some quaking aspen, elev. 1280 ft. Sec. 2, T45N, R8W. 46°24'44"N, 91°19'41"W. 31 May 2004. #90491-90525.

Loc. 4.: Wisconsin, Bayfield Co., Chequamegon National Forest, Rainbow Lake Wilderness. W side of wilderness SW of Rainbow Lake. Young red pine stand with few hardwoods, elev. 1350 ft. Sec. 2, T45N, R8W. 46°24'54"N, 91°19'40"W. 31 May 2004. #90526-90543.

Loc. 5.: Wisconsin, Bayfield Co., Chequamegon National Forest, Rainbow Lake Wilderness. N side of wilderness W of Frog Lake. Small hills with red oak, sugar maple, and white birch, elev. 1220 ft. Sec. 26, T26N, R8W. 46°26'36"N, 91°19'40"W. 31 May 2004. #90544-90583.

Loc. 6.: Wisconsin, Bayfield Co., Chequamegon National Forest, Rainbow Lake Wilderness. NE of Beaver Lake. Red pine, hemlock, sugar maple, and few white pine, elev. 1160 ft. Sec. 32, T46N, R7W. 46°25'10"N, 91°16'06"W. 1 June 2004. #90584-90613.

Loc. 7.: Wisconsin, Bayfield Co., Chequamegon National Forest, Rainbow Lake Wilderness. W of Flakefjord Lake south of trail. On ridge with white birch, sugar maple, and red oak, elev. 1230 ft. Sec. 6, T45N, R7W. 46°24'10"N, 91°17'06"W. 1 June 2004. #90614-90640.

Loc. 8.: Wisconsin, Bayfield Co., Chequamegon National Forest. Near Perch Lake Campground. In small black ash bog near road, elev. 1240 ft. Sec. 5, T46N, R7W. 46°24'07"N, 91°16'15"W. 1 June 2004. #90641.

Loc. 9.: Wisconsin, Bayfield Co., Chequamegon National Forest, Rainbow Lake Wilderness. SE side of Beaver Lake. Hemlock and maple forest, elev. 1140 ft. Sec. 32, T46N, R7W, 46°25'01"N, 91°16'00"W. 1 June 2004. #90642.

Loc. 10.: Wisconsin, Bayfield Co., Chequamegon National Forest, Rainbow Lake Wilderness. Ridge NE of Tower Lake. Broad ridge with sugar maple, red oak, white birch, and patches of young big tooth aspen, elev. 1250 ft. Sec. 25, T46N, R8W. 46°26'19"N, 91°18'18"W. 2 June 2004. #90643-90677.

Loc. 11.: Wisconsin, Bayfield Co., Chequamegon National Forest, Rainbow Lake Wilderness. W of Bellevue Lake below big curve in trail. Stream valley with old quaking aspen, sugar maple, and white birch, elev. 1200 ft. Sec. 30, T46N, R7W. 46°26'11"N, 91°17'52"W. 2 June 2004. #90678-90706.

Loc. 12.: Wisconsin, Bayfield Co., Chequamegon National Forest, Rainbow Lake Wilderness. Just N of Tower Lake N of trail. In ash bog with black ash and few red maple, elev. 1250 ft. Sec. 25, T46N, R8W. 46°26'00"N, 91°18'59"W. 3 June 2004. #90707-90730.

Loc. 13.: Wisconsin, Bayfield Co., Chequamegon National Forest, Rainbow Lake Wilderness. Between Frog Lake and Tower Lake. Hilltop above beaver pond with sugar maple, white birch, red oak, and old quaking aspen, elev. 1200 ft. Sec. 25, T56N, R8W. 46°26'16"N, 91°19'05"W. 3 June 2004. #90731-90754.

Appendix 2

GPS Readings for 1992 Rainbow Lake Collection Localities

Collection numbers are those of Clifford Wetmore. All collections are listed in ascending order by collection number and date of collection. The numbers at the beginning of each locality are the collection numbers. The GPS readings obtained in 2004 are at the end of the locality. Not all of the 1992 localities were revisited in 2004 and lack GPS readings. All localities are in Chequamegon National Forest, Bayfield County, Wisconsin.

Loc. 1 - 70424-70473: Near southwest corner of wilderness, NW of Wabigon Lake. On gentle hillside with maple, basswood, birch at top and white spruce and balsam fir at bottom. Sec. 12, T45N, R8W. 31 July 1992. 46°23'28"N 91°19'11"W

Loc 2. - 70474-70512: Near road on west side of wilderness west of Anderson Lake. In area of white pine and some hardwoods. Sec. 2, T45N, R8W. 31 July 1992. 46°24'26"N 91°19'52"W

Loc. 3 - 70513-70555: In northwest corner of wilderness. On knoll with red oak, white pine and some jack pine and white birch. Sec. 26, T46N, R8W. 31 July 1992. 46°26'23"N 91°20'29"W

Loc. 4 - 70556-70597: Northwest of Reynard Lake in SE part of wilderness. In bog with black spruce, yellow birch and some white pines. Sec. 7, T45N, R7W. 1 Aug. 1992.

Loc. 5 - 70598-70652: At southwest end of Clay Lake. On hillside above shore with sugar maple, basswood and white birch. Sec. 8, T45N, T7W. 1 Aug. 1992.

Loc. 6. - 70653-70690: Northeast of Bufo Lake. On ridge with red oak, sugar maple and some white birch. Sec. 6, T45N, R7W. 2 Aug. 1992.

Loc. 7. - 70691-70725: North of Clay Lake. At edge of tamarack swamp with tamarack and red maple in the swamp and with sugar maple and some white pines on higher ground. Sec. 5, T46N, R7W. 2 Aug. 1992. CHEM. ANAL. 46°24'13"N 91°16'39"W

Loc. 8. - 70726-70760: In northeast part of wilderness southwest of Bellevue Lake. At edge of black spruce swamp with black spruce in swamp and pine-oak-maple on side. Sec. 31, T46N, R7W. 3 Aug. 1992. 46°25'47"N 91°16'56"W

Loc. 9. - 70761-70799: South of Bellevue Lake at northeast corner of wilderness. On knoll with red oak and sugar maple and few white birch. Sec. 32, T46N, R7W. 3 Aug. 1992. 46°25'41"N 91°16'40"W

Loc. 10. - 70800-70847: Northwest of Bellevue Lake. In and along edge of ash bog with black ash, red maple and some white pine. Sec. 30, T46N, R7W. 4 Aug. 1992. 46°26'19"N 91°17'25"W

Loc. 11. - 70848-70890: West of Bellevue Lake, north of Tower Lake. On ridgetop with sugar maple, basswood and some red oak. Sec. 25, T46N, R8W. 4 Aug. 1992. 46°26'03"N 91°18'36"W

Loc. 12. - 70891-70916: Northeast of Tower Lake at bend in trail. In young quaking aspen stand near stream with quaking aspen, some cherry and some old quaking aspen. Sec. 30, T46N, R7W. 4 Aug. 1992. 46°26'10"N 91°18'03"W

Loc. 13. - 70917-70969: In swamp at northwest side of Tower Lake. Ash bog with black ash, some yellow birch and red maple. Sec. 25, T46N, R8W. 5 Aug. 1992. 46°25'58"N 91°18'58"W

Loc. 14. - 70970-71006: South of Frog Lake. On steep banks of gully with red oak, maples and white pine. Sec. 25, T46N, R8W. 5 Aug. 1992. 46°26'32"N 91°18'56"W

Loc. 15. - 71007-71052: West of Tower Lake at North Country Trail. On rolling upland with red oak, maples, white birch and some quaking aspen. Sec. 26, T46N, R8W. 6 Aug. 1992.

Loc. 16. - 71053-71075: At northwest corner of wilderness, southeast of Square Lake. In tamarack swamp west of North Country Trail with tamarack. Sec. 26, T46N, R8W. 6 Aug. 1992. CHEM. ANAL. 46°26'33"N 91°20'24"W

Loc. 17. - 71076-71125: On west side of wilderness northwest of Rainbow Lake. On side of ridge with red oak, white birch and some sugar maple. Sec. 35, T46N, R8W. 9 Aug. 1992. 46°25'38"N 91°19'52"W

Loc. 18. - 71126-71174: West of Rainbow Lake. In wet area with few tamarack, yellow birch, black ash, white pine and alders. Sec. 35, T46N, R8W. 9 Aug. 1992. 46°25'13"N 91°19'37"W

Loc. 19. - 71175-71211: At south end of Rainbow Lake. In bog with black spruce and tamarack. Sec. 36, T46N, R8W. 10 Aug. 1992.

Loc. 20. - 71212-71247: North of Rainbow Lake. In valley with basswood, sugar maple and some old quaking aspen. Sec. 36, T46N, R8W. 10 Aug. 1992.

Loc. 21. - 71248-71288: North edge of Lee Lake at southern edge of wilderness. In bog with black spruce and tamarack. Sec. 12, T45N, R8W. 11 Aug. 1992. CHEM. ANAL. 46°23'53"N 91°18'43"W

Loc. 22. - 71289-71343: On northeast side of Reynard Lake. On south facing hillside above bog with red oak, maples and white birch. Sec. 7, T45N, R7W. 11 Aug. 1992.

Loc. 23. - 71344-71398: West side of Beaver Lake. Along hillside above swamp with maple, white birch and hemlock. Sec. 32, T46N, R7W. 12 Aug. 1992.

Loc. 24. - 71399-71446: Northwest of Muck Lake and southwest of Beaver Lake. In bog area with some black ash, yellow birch, red maple and black spruce. Sec. 5, T45N, R7W. 12 Aug. 1992.

Loc. 25. - 71447-71495: Northeast of Anderson Lake. On ridge between trail and swamp with red maple, white birch and balsam fir. Sec. 1, T45N, R8W. 13 Aug. 1992.

Loc. 26. - 71496-71537: Near southwest corner of wilderness near Anderson Lake Trail. On level upland with sugar maple, white birch and red oak. Sec. 11, T45N, R8W. 13 Aug. 1992.
46°23'42"N 91°19'55"W

Loc. 27. - 71538-71594: At southeast corner of wilderness south of Wishbone Lake. In ash bog with black ash, yellow birch and red maple. Sec. 17, T45N, R7W. 14 Aug. 1992.

Appendix 3

Total species list for Rainbow Lake Wilderness. This list has been updated to current taxonomy and some species names may have changed since the original report.

Acarospora fuscata (Schrader) Arn.
Amandinea dakotensis (Magn.) P. May & Sheard
Amandinea polyspora (Willey) E. Lay & P. May
Amandinea punctata (Hoffm.) Coppins & Scheid.
Anaptychia palmulata (Michaux) Vainio
Arthonia caesia (Flotow) Körber
Arthonia didyma Körber
Arthonia fuliginosa (Schaerer) Flotow
Arthonia punctiformis Ach.
Arthonia radiata (Pers.) Ach.
Aspicilia caesiocinerea (Nyl. ex Malbr.) Arn.
Bacidia polychroa (Th. Fr.) Körber
Bacidia rubella (Hoffm.) Massal.
Bacidia sabuletorum (Schreb.) Lettau
Bacidia schweinitzii (Fr. ex Michener) A. Schneider
Bacidia suffusa (Fr.) A. Schneider
Biatora albohyalina (Nyl.) Bagl. & Carestia
Biatora helvola (Körber) Hellbom
Bryoria furcellata (Fr.) Brodo & Hawksw.
Bryoria trichodes (Michaux) Brodo & Hawksw.
Buellia arnoldii Servít & Nádv.
Buellia dialyta (Nyl.) Tuck.
Buellia schaereri de Not.
Buellia stillingiana J. Steiner
Calicium abietinum Pers.
Calicium parvum Tibell
Calicium trabinellum (Ach.) Ach
Caloplaca ahtii Söchting
Caloplaca brunneola Wetm.
Caloplaca cerina (Ehrh. ex Hedwig) Th. Fr.
Caloplaca chrysophthalma Degel.
Caloplaca holocarpa (Hoffm. ex Ach.) Wade
Candelaria concolor (Dickson) Stein
Candelaria fibrosa (Fr.) Müll. Arg.
Candelariella efflorescens Harris & Buck
Canomaculina subtinctoria (Zahlbr.) Elix
Cetraria americana (Spreng.) ined.
Cetraria pinastri (Scop.) Gray
Cetrelia olivetorum (Nyl.) Culb. & C. Culb.
Chaenotheca brunneola (Ach.) Müll. Arg.
Chaenotheca chrysocephala (Turner ex Ach.) Th. Fr.

Chaenotheca ferruginea (Turner & Borrer) Mig.
Chaenotheca stemonea (Ach.) Müll. Arg.
Chaenothecopsis debilis (Turner & Borrer ex Sm.) Tibell
Chaenothecopsis pusilla (Ach.) A. Schmidt
Chrysothrix candelaris (L.) Laund.
Cladonia caespiticia (Pers.) Flörke
Cladonia cenotea (Ach.) Schaerer
Cladonia cervicornis (Ach.) Flotow
Cladonia chlorophaea (Flörke ex Sommerf.) Sprengel
Cladonia coniocraea (Flörke) Sprengel
Cladonia cornuta (L.) Hoffm.
Cladonia cristatella Tuck.
Cladonia cryptochlorophaea Asah.
Cladonia digitata (L.) Hoffm.
Cladonia gracilis (L.) Willd.
Cladonia grayi G. Merr. ex Sandst.
Cladonia macilenta Hoffm.
Cladonia merochlorophaea Asah.
Cladonia mitis Sandst.
Cladonia parasitica (Hoffm.) Hoffm.
Cladonia pyxidata (L.) Hoffm.
Cladonia ramulosa (With.) Laund.
Cladonia rangiferina (L.) Wigg.
Cladonia rei Schaerer
Cladonia scabriuscula (Delise) Nyl.
Cladonia squamosa Hoffm.
Collema conglomeratum Hoffm.
Collema subflaccidum Degel.
Conotrema urceolatum (Ach.) Tuck.
Cyphelium lucidum (Th. Fr.) Th. Fr.
Dimerella pineti (Ach.) Vezda
Distopyrenis americana Aptroot
Eopyrenula intermedia Coppins
Evernia mesomorpha Nyl.
Flavoparmelia caperata (L.) Hale
Flavopunctelia flaventior (Stirton) Hale
Flavopunctelia soledica (Nyl.) Hale
Graphis scripta (L.) Ach.
Heterodermia galactophylla (Tuck.) Culb.
Heterodermia hypoleuca (Muhl.) Trevisan
Heterodermia speciosa (Wulfen) Trevisan
Hypocenomyce anthracophila (Nyl.) James & Schneider
Hypocenomyce friesii (Ach.) James & Gotth. Schneider
Hypocenomyce scalaris (Ach.) Choisy
Hypogymnia physodes (L.) Nyl.
Imshaugia aleurites (Ach.) S. Meyer

Ionaspis lacustris (With.) Lutzoni
Julella sericea (Massal.) Coppins
Lecania dubitans (Nyl.) A. L. Sm.
Lecanora allophana Nyl.
Lecanora caesiorubella subsp. *caesiorubella* Ach.
Lecanora carpinea (L.) Vainio
Lecanora circumborealis Brodo & Vitik.
Lecanora hybocarpa (Tuck.) Brodo
Lecanora impudens Degel.
Lecanora piniperda Körber
Lecanora pulicaris (Pers.) Ach.
Lecanora strobilina (Spengel) Kieffer
Lecanora symmicta (Ach.) Ach.
Lecanora thysanophora Harris in Harris & Tonsb.
Lecanora wisconsinensis Magn.
Lecidea nylanderi (Anzi) Th. Fr.
Lecidea plebeja Nyl.
Leptogium cyanescens (Rabenh.) Körber
Leptogium saturninum (Dickson) Nyl.
Leptogium teretiusculum (Wallr.) Arn.
Leptorhaphis epidermidis (Ach.) Th. Fr.
Lithothelium hyalosporum (Nyl.) Aptroot
Lobaria pulmonaria (L.) Hoffm.
Lobaria quercizans Michaux
Loxospora elatina (Ach.) Massal.
Loxospora pustulata (Brodo & Culb.) Harris
Megaspora verrucosa (Ach.) Hafellner & Wirth
Melanelia septentrionalis (Lyngé) Essl.
Melanelia subargentifera (Nyl.) Essl.
Melanelia subaurifera (Nyl.) Essl.
Micarea denigrata (Fr.) Hedl.
Micarea melaena (Nyl.) Hedl.
Micarea misella (Nyl.) Hedl.
Micarea prasina Fr.
Mycobilimbia berengeriana (Massal.) Hafellner & Wirth
Mycocalicium subtile (Pers.) Szat.
Myelochroa aurulenta (Tuck.) Elix & Hale
Myelochroa galbina (Ach.) Elix & Hale
Ochrolechia androgyna (Hoffm.) Arn.
Ochrolechia arborea (Kreyer) Almb.
Ochrolechia mexicana Vainio
Ochrolechia trochophora (Vainio) Oshio
Opegrapha varia Pers.
Pachyphiale fagicola (Hepp) Zwackh
Parmelia squarrosa Hale
Parmelia sulcata Taylor

Parmeliopsis ambigua (Wulfen) Nyl.
Parmeliopsis hyperopta (Ach.) Arn.
Parmotrema crinitum (Ach.) Choisy
Parmotrema margaritatum (Hue) Hale
Peltigera canina (L.) Willd.
Peltigera didactyla (With.) Laund.
Peltigera elisabethae Gyelnik
Peltigera evansiana Gyelnik
Peltigera membranacea (Ach.) Nyl.
Peltigera neckeri Hepp ex Müll. Arg.
Peltigera polydactylon (Necker) Hoffm.
Peltigera praetextata (Flörke ex Sommerf.) Zopf
Pertusaria amara (Ach.) Nyl.
Pertusaria macounii (Lamb) Dibben
Pertusaria multipunctoides Dibben
Pertusaria ophthalmiza (Nyl.) Nyl.
Pertusaria trachythallina Erichsen
Pertusaria velata (Turner) Nyl.
Phaeocalicium polyporaeum (Nyl.) Tibell
Phaeophyscia chloantha (Ach.) Moberg
Phaeophyscia ciliata (Hoffm.) Moberg
Phaeophyscia hispidula (Ach.) Essl.
Phaeophyscia imbricata (Vain.) Essl.
Phaeophyscia orbicularis (Necker) Moberg
Phaeophyscia pusilloides (Zahlbr.) Essl.
Phaeophyscia rubropulchra (Degel.) Essl.
Phlyctis argena (Sprengel) Flotow
Physcia adscendens (Fr.) H. Olivier
Physcia aipolia (Ehrh. ex Humb.) Fűrnr.
Physcia americana G. Merr.
Physcia millegrana Degel.
Physcia stellaris (L.) Nyl.
Physconia deterosa (Nyl.) Poelt
Physconia leucoleiptes (Tuck.) Essl.
Placynthiella dasaea (Stirton) Tønsberg
Placynthiella icmalea (Ach.) Coppins & James
Platismatia tuckermanii (Oakes) Culb. & C. Culb.
Porpidia crustulata (Ach.) Hertel & Knoph
Psilolechia lucida (Ach.) Choisy
Punctelia hypoleucites (Nyl.) Krog
Punctelia perreticulata (Räs.) Wilh. & Ladd
Punctelia rudecta (Ach.) Krog
Pyrenula pseudobufonia (Rehm) Harris
Pyrrhospora elabens (Fr.) Hafellner
Pyxine sorediata (Ach.) Mont.
Ramalina americana Hale

Rinodina archaea (Ach.) Arn.
Rinodina ascociscana Tuck.
Rinodina efflorescens Malme
Rinodina excrescens Vainio
Rinodina subminuta Magn.
Sarea resinae (Fr.) Kuntze
Scoliciosporum chlorococcum (Stenh.) Vezda
Sphinctrina turbinata (Pers. : Fr.) De Not.
Stenocybe pullatula (Ach.) Stein
Stereocaulon paschale (L.) Hoffm.
Stereocaulon saxatile Magn.
Strangospora microhaema (Norman) Anders.
Strangospora ochrophora (Nyl.) Anders.
Strigula submuriformis (Harris) Harris
Trapelia obtegens (Th. Fr.) Hertel
Trapeliopsis flexuosa (Fr.) Coppins & James
Trapeliopsis granulosa (Hoffm.) Lumbsch
Trapeliopsis viridescens (Schrader) Coppins & James
Usnea cavernosa Tuck.
Usnea ceratina Ach.
Usnea hirta (L.) F. Wigg.
Usnea lapponica Vainio
Usnea subfloridana Stirton
Xanthoria fallax (Hepp) Arn.
Xanthoria hasseana Räs.
Xanthoria ulophyllodes Räs.

Appendix 4

Element means (ppm) by species and year for three lichen species at Rainbow Lake Wilderness*

Element	Year					
	1992			2004		
	EVME	HYPH	PASU	EVME	HYPH	PASU
Al	597.22	535.09	670.89	483.28	344.66	545.91
B	2.60	2.84	4.83	2.78	3.61	5.76
Ca	834.38	17324.56	2653.39	1971.75	27168.78	3233.41
Cd	0.21	0.64	0.35	0.42	0.73	0.32
Cr	1.22	1.10	1.22	1.33	0.95	1.15
Cu	3.60	5.08	5.83	3.06	4.35	5.86
Fe	651.77	614.81	704.76	538.13	411.67	575.45
K	2177.97	3125.59	3600.11	1973.29	2525.57	2761.76
Mg	343.04	724.52	577.83	380.36	729.78	578.62
Mn	43.23	302.08	254.58	86.04	372.21	258.25
Na	31.40	29.05	25.44	27.82	23.94	22.16
Ni	0.99	1.02	1.28	1.26	1.40	1.48
P	535.90	797.79	1371.16	577.31	662.42	1029.11
Pb	6.33	14.29	13.47	2.26	6.83	6.58
S	1061.78	1002.78	1109.44	1051.67	1080.00	1142.22
Zn	43.01	78.44	84.49	32.38	74.34	84.73

*Species codes are explained in the text.

Appendix 5

Raw data from 2004 elemental analysis. Values are in ppm.

Locality	Species	Al	B	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	P	Pb	S	Zn
Clay L	EVME	423.63	1.74	1523.7	0.35	1.29	2.92	435.42	1668.70	319.04	53.30	23.18	1.25	408.57	1.93	1005	33.96
Clay L	EVME	458.92	1.81	1367.1	0.42	1.36	2.97	473.07	1625.20	315.21	46.11	26.71	1.48	402.15	1.87	720	35.62
Clay L	EVME	525.17	1.77	1678.8	0.34	1.36	2.95	562.53	1700.50	348.44	48.69	28.08	1.18	423.31	2.45	800	32.35
Clay L	HYPH	415.68	2.69	25702.0	0.72	0.94	4.35	479.13	2544.00	761.70	335.29	22.87	1.32	644.60	5.59	1150	87.48
Clay L	HYPH	439.88	2.72	24218.0	0.80	0.98	4.24	497.38	2315.10	676.87	301.95	21.91	1.43	574.00	6.96	1150	87.19
Clay L	PASU	648.05	4.36	3519.7	0.38	1.25	5.69	689.23	2583.10	609.96	275.28	23.37	1.34	908.11	7.05	1090	98.01
Clay L	PASU	729.80	4.29	3706.2	0.27	1.36	11.80	683.07	2277.70	496.45	238.22	22.04	1.37	792.37	7.00	1130	75.40
Lee L	EVME	487.96	2.63	2231.0	0.77	1.52	3.14	559.70	1618.70	336.98	53.88	28.72	1.27	474.43	2.27	1090	30.67
Lee L	EVME	570.41	2.20	2007.9	0.50	1.34	2.83	652.92	1529.10	356.13	43.61	32.26	1.08	493.20	2.76	1010	29.95
Lee L	EVME	498.67	4.32	1572.4	0.40	1.41	2.69	611.99	1713.40	345.10	51.00	31.72	2.08	529.86	2.40	1000	32.34
Lee L	HYPH	298.82	3.74	29235.0	0.72	0.99	4.24	373.38	2812.90	825.27	354.24	28.98	1.59	800.87	6.44	1040	78.08
Lee L	HYPH	367.91	3.60	30945.0	0.75	1.07	4.41	456.71	2755.30	791.33	350.32	30.95	2.09	752.40	6.85	1025	85.92
Lee L	HYPH	350.50	3.30	29371.0	0.85	0.90	4.29	421.10	2682.40	780.48	441.03	23.84	1.36	642.97	6.67	1000	78.42
Lee L	PASU	486.36	6.22	3084.9	0.29	1.08	4.44	546.68	2677.70	648.84	209.36	21.73	1.40	1066.50	6.11	1000	90.15
Lee L	PASU	489.77	4.10	3162.0	0.25	1.05	4.05	548.49	2301.80	548.64	224.54	22.80	2.05	768.12	5.79	975	85.09
Lee L	PASU	595.74	4.27	2992.5	0.31	1.22	5.89	622.54	2688.50	537.65	242.88	23.40	1.37	991.39	6.52	1080	96.02
N Country Tr	EVME	477.67	3.24	1981.8	0.34	1.36	3.35	538.19	2481.95	442.90	135.10	27.63	1.06	720.70	2.18	1360	31.32
N Country Tr	EVME	442.84	3.58	2564.7	0.29	1.13	3.29	497.15	2776.50	483.60	172.16	25.58	0.90	880.81	2.16	1280	31.32
N Country Tr	EVME	464.21	3.76	2818.4	0.34	1.25	3.39	512.19	2645.60	475.86	170.53	26.52	1.03	862.74	2.30	1200	33.89
N Country Tr	HYPH	329.96	4.13	27975.0	0.75	0.95	4.25	408.95	2584.50	709.01	436.84	21.34	1.16	660.20	8.24	810	62.66
N Country Tr	HYPH	354.30	4.56	25395.0	0.71	0.96	4.59	424.67	2653.60	737.79	414.90	22.63	1.24	676.13	8.37	1125	65.63
N Country Tr	HYPH	324.78	5.33	31922.0	0.79	0.87	4.81	402.93	2703.40	720.54	463.13	24.43	1.21	716.45	8.26	1310	67.66
N Country Tr	HYPH	220.12	2.38	19756.0	0.53	0.86	3.97	240.75	1678.90	565.07	252.20	18.47	1.22	494.18	4.07	1110	56.00
N Country Tr	PASU	494.14	6.86	3132.9	0.39	1.07	5.79	504.58	3204.20	561.10	296.63	20.74	1.25	1143.30	6.76	1300	75.89
N Country Tr	PASU	477.35	6.95	3031.5	0.32	1.00	5.09	501.18	3342.10	600.05	293.53	20.03	1.33	1346.70	6.00	1360	68.00
N Country Tr	PASU	541.14	9.49	3097.8	0.35	1.07	5.58	580.79	3257.10	596.49	342.02	22.97	1.72	1346.20	7.87	1310	71.80
N Country Tr	PASU	450.84	5.30	3373.2	0.28	1.21	4.40	502.53	2523.60	608.41	201.79	22.34	1.49	899.33	6.10	1035	102.21

