

EFFECTS OF ATMOSPHERIC ACID DEPOSITION  
ON WATERSHED/LAKE ECOSYSTEMS OF ISLE ROYALE  
AND MICHIGAN'S UPPER PENINSULA

Robert Stottlemeyer  
Department of Biological Sciences  
Michigan Technological University  
Houghton, MI 49931

1983 PROGRESS REPORT

Submitted in  
February 1984

Contributors were

Darcy Rutkowski  
David Hanson, Jr.

## INTRODUCTION

What follows is a report of research accomplishments for FY 1983. The results and discussion relate principally to four core areas: mineral nutrient input/output budgets, estimates of terrestrial biomass, lake chemistry and primary productivity, and anion mobility in forest soils. Progress in other core areas is covered in the February 1984 update of the Status of Core Requirements (Appendix A).

A major frustration during the past year was loss of our most "sensitive" watershed ecosystem due to human manipulation. The system that was being monitored, Central Lake, complemented the Isle Royale sites nicely since its vegetation and bedrock were very similar to the Isle Royale sites, but it only had a mean alkalinity of about 135 $\mu$ eq. This site was monitored for over a year. Fortunately, detailed and expensive study on the site had not begun since the protection of the site was always somewhat in question. Last summer we began another site search deciding that unless a legally protected site could be found there would be no further study on a poorly buffered site (Isle Royale apparently has no lake/watersheds with mean alkalinities less than 200 $\mu$ eq  $\text{CaCO}_3$ ). However, an excellent site, Trout Lake, was located in the granitic Huron Mountains. This site will be fully instrumented this spring for continuous and intensive study. It is quite accessible at least by Isle Royale standards, and it complements the Isle Royale sites.

During 1983 some additional survey work was also done on Isle Royale especially once it became known that the Central site on the Keweenaw Peninsula was in jeopardy. An additional extensive lake/watershed survey was done in June. One additional site, Noname Lake which is about 10km from the Wallace Lake site, was monitored for the entire summer, and some additional vegetation work done on it. However, after looking over the data sets it now appears that our two original Isle Royale choices, Wallace and Sumner Lakes, were the best in terms of representing the range of lake chemistry characteristics on Isle Royale. The data that have been collected on the additional survey sites have been carefully kept on computer files.

One lake which was surveyed starting with spring runoff was Newt Lake, a small high elevation (by Isle Royale standards) lake which has no perennial surface stream inputs. Seasonally, it contributes to Sumner Lake. Newt has some of the highest alkalinity and Ca concentrations found on the island. It demonstrates the apparent dominating influence of the scattered marine glacial till on stream and lake

water chemistry of Isle Royale and sections of Minnesota.

In addition, this year we began some checks on anion/cation balances and found an anticipated anion deficiency which we thought would be organic acids especially during spring runoff periods. However, this is not yet clear. Data collected on  $\text{SiO}_2$  by the USGS and ourselves show that when this anion is added to the suite near-perfect balance is obtained. Further observation is needed, however, especially on organic acids during periods of high discharge. This is the subject of an ongoing study in a small watershed on the Keweenaw Peninsula. Depending upon the results this spring the issue might also be examined more closely in the future on the Isle Royale sites.

A Scope of Work statement outlining the areas for emphasis during FY 1984 is currently out on review (Appendix B). This year three things will be emphasized: aquatic biota baselines, completion of the terrestrial plot data sets, and completion of remote area field instrumentation.

#### PRELIMINARY INPUT/OUTPUT BUDGETS FOR SELECTED INORGANIC ION SPECIES

##### Methods

Precipitation chemistry has been monitored since May 1979 using bulk collectors on the southwest end of Isle Royale. This monitoring station continues to operate supplemented by a NADP station operated for six months during the summer. Bulk precipitation chemistry has been monitored in the immediate vicinity of Wallace Lake also since May 1979. A complete data set was not, unfortunately, obtained at this site during 1980. This monitoring continues, and it is now complemented by a Aerochem Metrics sampler (on loan) which is battery operated during the period the island is occupied.

Samples are collected weekly during the time of island occupancy, and much less frequently during the period November to April. Continuous Belfort collectors and hygrothermographs are ran at both stations all year, and these reveal that the vast majority of precipitation falling in bulk collectors during the "off season" is snowfall. The less frequent winter sampling protocol therefore probably does little to effect precipitation sample quality.

##### Results for 1983

$\text{H}^+$  ion continues to dominate the cationic strength of

precipitation (weighted mean pH is 4.5 - 4.6 depending on whether bulk or w/d sampler). In the five years of sampling no significant trend has been observed. Preliminary estimates of weighted mean precipitation concentrations for selected ionic species during FY 1983 are as follows:

| Ion             | mg/l |
|-----------------|------|
| Ca              | 0.18 |
| K               | 0.07 |
| NO <sub>3</sub> | 1.68 |
| SO <sub>4</sub> | 3.20 |

Converting these preliminary values into input (kg/ha) we have the following values for FY 1983.

|                 |       |
|-----------------|-------|
| Ca              | 1.74  |
| K               | 0.78  |
| NO <sub>3</sub> | 14.95 |
| SO <sub>4</sub> | 24.42 |

Converting concentration to equivalents the SO<sub>4</sub>/NO<sub>3</sub> ratio is 2.46. This ratio might change somewhat since it now appears the SO<sub>4</sub> concentrations obtained in the laboratory have been somewhat high due to a consistently low standard conversion factor. This is fully documented and the change will be made shortly.

Comparing these values to the longest-term record in the US (Hubbard Brook) we find that Ca and K values are almost identical which is somewhat surprising since the Upper Midwest is known as an area where dust inputs from the agricultural practices in the Great Plains are quite high. However, our record is only for the year. Our values for NO<sub>3</sub> and SO<sub>4</sub> are both somewhat higher than the 1963-1974 record for Hubbard Brook which is expected since air quality conditions, at least for NO<sub>3</sub>, have probably deteriorated since the earlier period (Verry 1983).

Like many of the NADP stations the Isle Royale site has a relatively poor correlation between hydrogen ion concentration and SO<sub>4</sub> concentration ( $r = 0.53$ ), but there is a very high correlation for the Houghton NADP site ( $r = 0.97$ ).

Isle Royale inorganic outputs from the coterminous Wallace and Sumner Lake watershed ecosystems, which are on nearly identical bedrock formations, appear to reflect edaphic differences. Selected ionic outputs (kg/ha) for these two lakes from October 1982 to October 1983 are as follows:

## Wallace

| Ion             | Kg/Ha |
|-----------------|-------|
| Ca              | 85.1  |
| K               | 1.2   |
| NO <sub>3</sub> | 1.9   |
| SO <sub>4</sub> | 27.4  |

## Sumner

|                 |       |
|-----------------|-------|
| Ca              | 119.6 |
| K               | 0.9   |
| NO <sub>3</sub> | 0.3   |
| SO <sub>4</sub> | 31.4  |

The most striking differences between these two lake/watershed systems are the outputs of Ca and NO<sub>3</sub>. Mg values for Sumner are also significantly higher than for Wallace. To date the only explanation for this must be edaphic conditions. We do not yet have enough soils data on Sumner though to make a comparison. Ca output from Wallace exceeds input by almost 50x, and output from Sumner exceeds input by 68x. K output only slightly exceeds input for this period with the ratio being 1.6x for Wallace and 1.1x for Sumner. NO<sub>3</sub> output from both systems is much reduced over inputs which is typical for Upper Midwest systems it appears. Wallace output was only 13% of input and Sumner was only 2%. The Wallace drainage has a much higher frequency of *Alnus* in it which could account for the higher release, but data on stream input into the lake must be looked at first before this assumption can be substantiated. In general, these outputs of NO<sub>3</sub> are much lower than those observed in other streams on Isle Royale and in the Upper Peninsula and elsewhere. But the lakes incorporated in these systems are very shallow (see following section) and are ideal places for high biological incorporation of this often limiting nutrient.

SO<sub>4</sub> output from both watersheds is quite similar. Output of this anion exceeds input by 1.1 for Wallace and 1.3 for Sumner. These values are somewhat lower than those observed for streams which generally have a net loss ratio of about 1.4 - 1.5. However, the fact that SO<sub>4</sub> is on the whole leaving a lake/watershed system, even systems that are completely vegetated, clearly keeps open the possibility of this anion leaching essential cation species from forest soils. How much of this output is coming from precipitation and how much from the decomposition of organic matter is not presently known, but is the subject of a graduate student

study underway (see following section).

## VEGETATION PLCT AND BIOMASS ANALYSES

### Introduction

Isle Royale lies within the vegetational transition zone between the northern boreal forest found on the north shore of Lake Superior and the eastern deciduous forest which predominates up to the south shore of Lake Superior (Braun, 1950; Shelford, 1963; Larsen, 1980). Two major forest types characterize the island's vegetation: the boreal forest formation which is dominated by *Picea glauca* (Moench.) Voss and *Abies balsamea* (L.) Mill. occurs in the proximity of Lake Superior; and the deciduous forest formation dominated by *Acer saccharum* Marsh and *Betula lutea* Michx. which is found in the inland-upland areas where lake influence is diminished. Linn (1957) has extensively studied the transition zone between the two climax types.

Fire has been an important factor in the history of Isle Royale. Prior to acquisition of the island by the National Park Service during the 1930's, mining was of economic importance and the burning of large tracts of forest to expose mineral deposits was not an unusual event in the mid and late 1800's. Since park establishment the only fire of great significance was the catastrophic fire of 1936 that burned approximately one-third of the island (Linn, Sumner and Sprugel, 1966). As a result of this fire history a great portion of the vegetation of Isle Royale is a mosaic of seral stands in varying successional stages.

Classical botanical research took place on the island in the early part of this century (Cooper 1911, 1912, 1913; Adams, 1909) but was primarily taxonomically oriented. More recently studies have been completed concerning the flora and vegetational ecology of the boreal forest regions of the island (Janke, 1977-1983) and the variation in herbivore pressure on vegetation types for much of Isle Royale (Janke, 1976; Krefting, 1974; Peterson, 1977). However, there are little if any data on productivity and biomass of either aquatic or terrestrial systems on the island.

The objectives of this study are twofold: characterize the vegetational composition and phytosociology of the two experimental watersheds; and quantify and compare the aboveground standing biomass of the tree, shrub/tall herb, and herbaceous vascular plant strata of the watersheds. These findings will be further utilized in the

establishment of nutrient budgets for the two watersheds in the future.

### Study Area

Species composition and biomass data were collected in Wallace and Noname watersheds on Isle Royale. With loss of the sensitive Central drainage Noname Lake was being considered as a candidate sensitive system. However, a subsequent examination of the year's chemistry indicates that Wallace, Sumner, and Trout make up the best spectrum.

The Wallace and Noname lake/watershed ecosystems are 170.2 ha and 45.6 ha in area respectively. They are dominated by boreal forests with Noname Lake's watershed almost exclusively conifers (jack pine and spruce-fir) and Wallace Lake's watershed a mixture of birch, aspen and spruce-fir. A portion of the Wallace Lake watershed burned in the fire of 1936. There is no evidence of fire in the last 125 years in the remainder of the Wallace Lake or Noname Lake watersheds. Both have middle preambrian metamorphosed volcanic substrates which are thought to be slightly less sensitive than the underlying early preambrian granites which dominate the surface features of the Canadian Shield (NADP, 1982). The geology of the island has been documented by Huber (1975). Annual precipitation input to Isle Royale (76 cm) exceeds that of the north shore of Lake Superior (68 cm) but is much less than that which falls on the south shore (88 cm) at an equivalent elevation. Based on climatic data collected for several decades it appears that Isle Royale is more similar to the north shore of Lake Superior than the south shore, but the lake still dominates the climate of the region when one examines regional temperature and precipitation regimes. The two sites are a good study pair as they are very close spatially (within 5 km), are very similar in elevation and proximity to Lake Superior, receive the same precipitation inputs, but differ fundamentally in terms of vegetation type and extent of glacial till deposits.

### Methods

Vegetation sampling was undertaken in the Wallace Lake and Noname Lake watersheds with the establishment of two north-south transects in each watershed. The two transects divided each lake approximately in thirds. A stratified random sampling design was utilized to locate two tenth-

hectare (50m x 20m) vegetation plots on each transect. Diameter at breast height (1.5m) was recorded for all tree species (dbh > 2.5cm) in the canopy and understory. Height of all trees was measured with a clinometer. Increment cores were obtained from all trees with a dbh greater than 7 cm in two 10m x 12m subplots in each 0.1ha plot. These tree cores were frozen to minimize decomposition and will be analyzed to determine tree age. Saplings (dbh < 2.5cm, height > 0.5m) were recorded as to species and height in a 2m x 5m subplot located in each of the four corners of the 0.1ha plot and the same was done for seedlings (tree species < 0.5m tall) in 1m x 1m subplots nested in the sapling plots. A 50m long transect was established in the center down the long axis of the plot along which five 1m<sup>2</sup> subplots were established at predetermined locations. Herbaceous vascular plant cover was estimated for each non-tree species < 0.5m in height in each of the five subplots. Coverage of taller herbs and shrubs all exceeding 0.5m in height was estimated in three 2m<sub>2</sub> x 2m subplots which were nested outside three of the five 1m<sup>2</sup> subplots. Stem counts were obtained for all species except grasses and sedges in each stratum and current growth of shoots of herbs and shrubs was clipped and bagged by species for each subplot. There was no attempt to identify grasses and sedges to genus and all species from the families Gramineae and Cyperaceae were lumped together in one category.

Fresh weights were obtained to the nearest 0.5 grams for each species and then any species which occurred in more than one subplot were combined to make a composite for that major plot. The tissue samples were air dried to prevent decomposition until they could be transported to the lab for further analysis. In the lab samples were dried at 65°C for 24 hours and ground in a Wiley Mill to pass a 60-mesh stainless steel sieve. The ground material was dried an additional 72 hours at 65°C, placed in plastic whirl-pac bags and stored at 2°C until a nutrient analysis can be completed for those species contributing significantly to the biomass of the watershed. To minimize contamination polyethylene gloves were worn for all sample collection and handling.

The aboveground standing biomass for trees in the two watersheds was estimated using published equations for predicting biomass for the various species. These equations are listed in Appendix C. Data are being collected in the experimental watersheds to develop volume equations specific to Isle Royale.

## Vegetation Chemical Analyses

Subsamples from all plant species were collected and are currently being analyzed. No results are yet available.

Samples of herbaceous tissue are assessed for Ca, Mg, Na, K,  $\text{NH}_4$ ,  $\text{PO}_4$ ,  $\text{NO}_3$ , and  $\text{SO}_4$ . Drying, grinding, and extracting procedures closely follow those outlined by Bormann and Likens (1970). Citrus leaves from the National Bureau of Standards are used as standards and for determining the efficiency of nutrient recovery when experimenting with different digestion and extraction methods. They are processed in an identical manner to the samples, and replicates are also ran. Samples are handled with plastic gloves and stored frozen in clean plastic bags. Glassware is washed in concentrated  $\text{HNO}_3$  and rinsed with deionized water (conductivity  $< 1.0 \mu\text{mhos}/\text{cm}^2$  at  $20^\circ$ ). Polyethylene storage bottles are washed in dilute HCl and rinsed several times with deionized water. Plant tissue is ground in a Wiley Mill with a 60 mesh screen. Ground material is dried for 72 hours at  $65^\circ\text{C}$  and 0.5 gram subsamples weighed to the nearest 0.01 mg. The subsamples are placed in clean, dry crucibles and, starting with a cold muffle furnace, ashed for 2 hours at  $500^\circ\text{C}$ .

For cation analyses, about 1 ml deionized water and 1.0 ml reagent grade 6 N HCl are added to the crucible and brought to the boiling point over a hotplate. The contents are then diluted with deionized water to 100 ml in a clean volumetric flask and filtered through a  $0.45 \mu$  membrane filter. The filtrate was diluted 100x and analyzed on a Dionex Model 10 Chromatograph.

## Results

The Wallace Lake and Noname Lake watersheds differ fundamentally in terms of vascular flora. Total aboveground biomass for the herb, shrub and tree strata is estimated to be 83,406 kg/ha in the Wallace Lake watershed and 37,588 kg/ha in the Noname Lake watershed (Tables 1 & 2). Figure 1 compares the distribution of biomass between the herb, shrub and tree strata in the two watersheds. Although there was a significant difference in total biomass between the two watersheds, the distribution of biomass among the vegetation strata was almost identical. Those species contributing at least 3% to the total biomass of the herb, shrub or tree strata in the respective watersheds are listed in Tables 1 and 2. Importance values for herbaceous species were calculated for each plot as the sum of relative weight of current growth and relative cover percentage.

Sample plots in the Wallace Lake watershed contained a total of 58 species of vascular plants: 51 herbs and shrubs and 8

Table 1. Cover percentages, densities and biomass of aboveground current growth for the Wallace Lake and Noname Lake watersheds. Species listed in the table are those contributing at least 3% to the biomass of the herb or shrub/tall herb strata. Species present in the watersheds but contributing <3.0% to the above-ground biomass are listed in Appendix II.

| WALLACE LAKE WATERSHED |         |                  |                   | NONAME LAKE WATERSHED |         |                  |                   |
|------------------------|---------|------------------|-------------------|-----------------------|---------|------------------|-------------------|
| Species                | Cover % | Density stems/ha | Weight kg/ha + SE | Species               | Cover % | Density stems/ha | Weight kg/ha + SE |
| HERBS                  |         |                  |                   | HERBS                 |         |                  |                   |
| Aster macrophyllus     | 40.4    | 641,500          | 394.2 + 89.3      | Lycopodium annotinum  | 0.9     | 11,500           | 61.8 + 40.5       |
| Lycopodium clavatum    | 2.1     | 9,500            | 62.8 + 51.2       | Aster macrophyllus    | 5.2     | 208,000          | 59.2 + 14.6       |
| Grasses/Sedges         | 5.8     | ---              | 52.8 + 26.9       | Grasses/Sedges        | 3.2     | ---              | 48.3 + 22.6       |
| Rubus parviflorus      | 7.3     | 38,500           | 47.1 + 19.0       | Viburnum edule        | 0.7     | 9,500            | 39.2 + 39.2       |
| Lycopodium obscurum    | 2.0     | 86,500           | 46.7 + 35.3       | Diervilla lonicera    | 2.2     | 28,000           | 38.5 + 17.7       |
| Clintonia borealis     | 8.4     | 94,500           | 40.7 + 17.0       | Cornus canadensis     | 2.9     | 218,500          | 25.6 + 15.5       |
| Aralia nudicaulis      | 6.7     | 44,500           | 32.3 + 3.7        | Amelanchier sp.       | 0.2     | 2,500            | 24.8 + 21.5       |
| Lycopodium annotinum   | 0.8     | 4,500            | 31.0 + 18.7       | Rosa acicularis       | 0.4     | 18,500           | 19.6 + 18.7       |
| Linnaea borealis       | 1.4     | 56,500           | 29.5 + 21.1       | Lycopodium clavatum   | 0.3     | 3,500            | 17.6 + 12.4       |
| SHRUBS/TALL HERBS      |         |                  |                   | SHRUBS/TALL HERBS     |         |                  |                   |
| Rubus parviflorus      | 12.3    | 55,000           | 298.3 + 117.0     | Lonicera canadensis   | 0.4     | 3,000            | 54.7 + 54.7       |
| Osmunda claytoniana    | 2.5     | 2,500            | 95.1 + 95.1       | Viburnum edule        | < 0.1   | 1,000            | 20.3 + 20.3       |
| Rubus strigosus        | 1.4     | 8,000            | 60.6 + 60.6       | Lonicera dioica       | 0.1     | 1,500            | 9.9 + 9.9         |
| Viburnum edule         | 0.3     | 3,000            | 54.6 + 25.1       | Rubus parviflorus     | 0.1     | 1,000            | 6.9 + 6.9         |
| Pteridium aquilinum    | 0.5     | 1,000            | 30.5 + 30.5       | Grasses/Sedges        | < 0.1   | ---              | 5.2 + 5.2         |
| Thalictrum dasycarpum  | 0.2     | 2,000            | 18.7 + 18.7       |                       |         |                  |                   |

Table 2. Basal area, densities and biomass of aboveground current growth of trees for the two watersheds.

| Species             | Basal Area<br>cm <sup>2</sup> /ha | Density<br>stems/ha | Weight<br>kg/ha + SE |
|---------------------|-----------------------------------|---------------------|----------------------|
| WALLACE LAKE        |                                   |                     |                      |
| Betula papyrifera   | 58,046                            | 222.5               | 31,114.93 + 27.68    |
| Populus tremuloides | 49,935                            | 70.0                | 18,219.04 + 80.57    |
| Picea glauca        | 43,098                            | 262.5               | 16,596.30 + 31.64    |
| Abies balsamea      | 12,908                            | 90.0                | 4,249.19 + 26.19     |
| Alnus rugosa        | 18,688                            | 717.5               | 4,158.40 + 00.68     |
| Thuja occidentalis  | 16,136                            | 90.0                | 3,794.90 + 22.94     |
| Picea mariana       | 9,285                             | 20.0                | 3,555.12 + 87.80     |
| Salix spp.          | 1,015                             | 17.5                | 238.98 + 8.83        |
| NONAME LAKE         |                                   |                     |                      |
| Pinus banksiana     | 78,551                            | 435.0               | 31,594.14 + 40.19    |
| Picea mariana       | 17,616                            | 320.0               | 4,347.43 + 9.19      |
| Betula papyrifera   | 3,620                             | 100.0               | 1,063.00 + 12.91     |
| Abies balsamea      | 354                               | 20.0                | 56.05 + 4.67         |

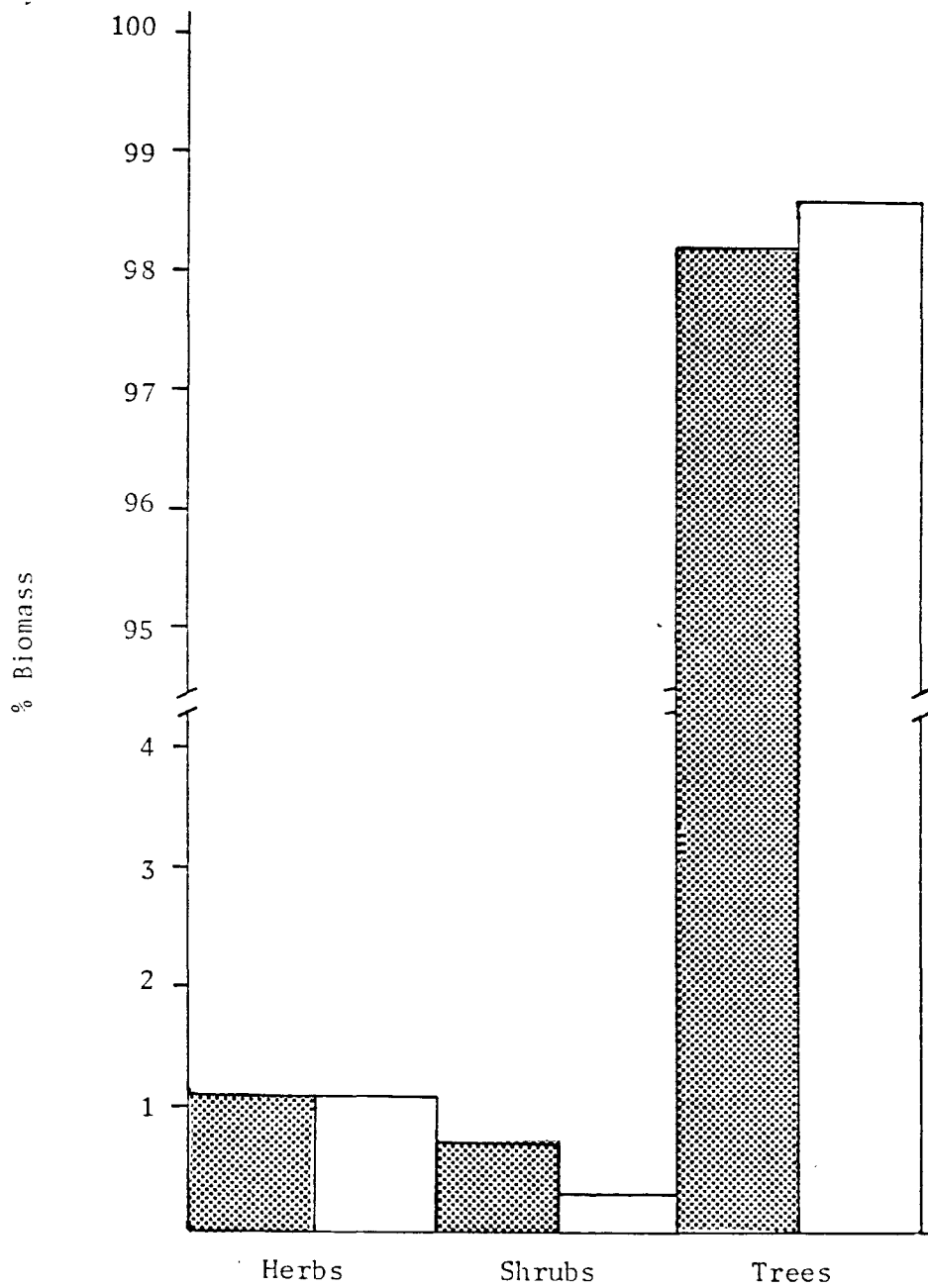


Figure 1. A comparison of biomass within the herb, shrub/tall herb and tree strata for the Wallace Lake (shaded) and Noname Lake watersheds.

trees. Based on Importance values *Aster macrophyllus* was the dominant species in all four sample plots and contributed over 45% to the biomass of the herb layer. The shrub stratum was dominated by *Rubus parviflorus*, which contributed 49% to the biomass and was also the dominant species in all four sample plots.

Fewer species were encountered in sampling at Noname Lake in comparison to Wallace. There were 37 herbs and shrubs and only 4 species of trees for a total species count of 41. The biomass of the herbaceous layer was not dominated by a single species in the Noname watershed as it was at Wallace Lake. *Lycopodium annotinum* and *Aster macrophyllus* each contributed approximately 14% of the biomass. Examining Importance values, here again as in the Wallace Lake watershed, *Aster macrophyllus* was the dominant species on two of the four sample plots and second in importance on the remaining two plots. *Lycopodium annotinum* and Grasses/Sedges were the dominant species on each of the other two plots. In the shrub/tall herb stratum *Lonicera canadensis* and *Viburnum edule* contributed 54% and 20% to the biomass respectively. However, there were no shrubs/tall herbs encountered in sampling at two of the four plots at Noname and in a third plot only one species was encountered in this vegetation layer. Therefore, most of the biomass of shrubs/tall herbs was in a single sample plot.

## Discussion

In terms of species composition, the Wallace and Noname Lake watersheds seem to be fairly representative of boreal forests in the region. Maycock (1961) found *Rubus parviflorus* to be the only shrub which occurred in all four of the boreal forest stands he studied on the Keeweenaw Peninsula to the south of Isle Royale. *Lonicera canadensis* was the second most important shrub in his stands. These two were also the dominant species in the shrub/tall herb layers of the Wallace and Noname watersheds respectively. He also reports *Aster macrophyllus*, *Maianthemum canadense*, *Mitella nuda*, *Carex pedunculata* and *Aralia nudicaulis* as the only herbs which occurred in all four of the stands he studied. With the exception of *Carex pedunculata*, these species occur with exceptional consistency in our sample plots also. However, *Maianthemum canadense* and *Mitella nuda*, being such small individuals, do not contribute much to the biomass. In fact, all four species occur with 100% constancy in the

four sample plots at Wallace Lake and *Aster macrophyllus* and *Maianthemum canadense* also occur in all of the Noname Lake plots.

The aboveground current growth in the herb and shrub/tall herb layers together totalled 1479 kg/ha in the Wallace Lake watershed and 528 kg/ha in the Noname Lake watershed. Figure 1 shows that in both cases these two strata combined contribute less than 2% to the total aboveground biomass in each of the watersheds. In comparison, biomass of the herb and shrub layers of the control northern hardwood forests at Hubbard Brook was estimated to be 162 kg/ha (Siccama, Bormann, and Likens, 1970). They found the fraction of biomass in shrubs and herbs to be less than 1% and these findings were comparable to those of high-elevation broad-leaf forests in the Great Smoky Mountains.

Although the herb and shrub strata at Hubbard Brook contain less in the way of biomass than do those strata in either the Wallace or Noname watersheds, Whittaker, Bormann, Likens, and Siccama (1974) report the aboveground weight for trees at Hubbard Brook to be 132,810 kg/ha. This is considerably higher than our estimates of 81,927 kg/ha at Wallace and 37,061 kg/ha at Noname. Therefore, the smaller amount of biomass on the forest floor at Hubbard Brook might be attributed to the denser forest canopy.

The variability among sample plots is evident in the fairly large standard errors for mean biomass of individual species in the two watersheds (see Table 1). However, our standard error values are comparable to those from similar studies and are only slightly higher than those calculated by Siccama et al. (1970) in their Hubbard Brook watershed. Unless the vegetation of the entire watershed was uniform one would expect a certain amount of variability due to placement of sample plots in different vegetation types. Our higher values can partially be attributed to the larger size of our watersheds, 176 and 46 ha in the Wallace and Noname Lake watersheds respectively, as compared to 13.2ha at Hubbard Brook. In addition to size differences there was also a significant difference in sampling intensity in the Isle Royale study when compared to Hubbard Brook. For example, our herbaceous biomass values were calculated from data collected on 20, 1m x 1m subplots in each watershed while the Hubbard Brook data were collected from 208 such plots. Also one must keep in mind that the Hubbard Brook site is basically an eighty-year old successional forest which has quite low species diversity in the understory. The Isle Royale sites are in more diverse mature boreal forested ecosystems with very diverse understory conditions.

At Hubbard Brook the mean standard error for all herbaceous species was 43% while our values for Wallace and Noname were 50.6 and 66% respectively. Our variation for shrub species is considerably above their values since we often have a species only occurring on one of four plots in a watershed. This reflects the high spatial variability characteristic of this mature vegetation on a recently glaciated substrate.

Biomass as it relates to economic forest productivity is a familiar concept and has been an essential part of forest management for years. More recently however, biological forest productivity has come of interest with the study of total ecosystems and concern for energy and nutrient budgets (Stanek and State, 1978).

There are several published regression equations for determining biomass of the various tree species. The equations are based on allometry, the concept that two dimensions or weights of organs grow in such a way that the ratio between their geometric growth rates remains constant over considerable periods of time (Peterson, Chan and Cragg, 1970). Stanek and State (1978) have compiled the equations available in the literature for estimating the biomass of individual plants (trees, shrubs, lesser vegetation) and their components (leaves, branches, bole, bark, wood, roots, etc.). Most authors arrived at these regression equations with the use of destructive sampling methods. These involved the actual removal of trees and intensive measurements of various components and then sectioning or taking subsamples from the components to obtain oven-dry weights. However, to facilitate practical application the resulting equations use easily determinable characteristics (such as diameter at breast height or tree height) to determine biomass.

Many researchers stress the equations they have developed are not necessarily applicable to all sites (Moir and Francis, 1972; Doucet, Berglund and Farnsworth, 1976; Peterson, et al., 1970; Whittaker, et al., 1974). Site quality and stand age are important in forming the equations, therefore a single equation will not sufficiently describe the biomass of a certain species for all sites. There is also some discrepancy in the literature as to which measurement is the best predictor of biomass. Peterson et al. (1970) found the product of the square of the diameter at breast height and height ( $D^2H$ ) to be the best predictor of aboveground biomass in the aspen stands they studied. In his study of biomass in jack pine stands, Hegyi (1972) used diameter at breast height alone. He found that the use of other independent variables (i.e. height or diameter<sup>2</sup> x

height, etc.) did not appreciably improve the regression equations.

Destructive sampling insures accuracy in calculating standing biomass particularly when the sample size is quite large. However, this type of sampling is impossible in a protected area such as Isle Royale. Therefore, we've had to rely on published equations for determining biomass of the tree stratum in our watersheds. In choosing the appropriate equations several things were taken into consideration. First of all, we looked for research that had been carried out in similar forest types with similar site quality. There apparently have been no studies of this type in the Upper Great Lakes region and no single author had equations covering the nine species from our two watersheds. Another factor taken into consideration is that the regression equations are only appropriate for a defined range of diameters. When they are applied to trees with diameters not falling within this range the predictions may be invalid. There is also a lot of variation in the particular tree components for which one can obtain biomass for the various species. We were consistent in utilizing equations which predicted biomass for the tree or whole plant above ground level. Therefore, our results do not include that portion of the biomass contributed by the roots. Previous studies have shown root biomass to be 18-21% of the aboveground biomass (Whittaker et al., 1974).

After taking all these factors into consideration we chose the most appropriate equations. However, none of the published equations for black spruce (*Picea mariana* (Mill.) BSP.) were appropriate for use in our watersheds. In this case the equation for white spruce was substituted (Baskerville, 1965). The equation for western red cedar (*Thuja plicata* Donn) was utilized for those white cedar trees with diameters exceeding 14.0 cm (Kurucz, 1961). Also, in the case of quaking aspen (*Populus tremuloides* Michx.) and white spruce several of our trees had diameters which exceeded the range for which the equations were appropriate. We feel that the published regression equations were sufficient in predicting standing biomass for the trees in our watersheds. This is supported by the fact that our highest standard error of the mean was 8% of the biomass for that species and that 8 out of the 12 predictions had standard errors under 1%. However, we plan to verify our choice of equations by collecting intensive measurements on recent windfalls from each watershed to test how well our form class data match that used by the authors of the equations we're utilizing.

## LAKE PHYSICAL PARAMETERS AND PRIMARY PRODUCTIVITY

### Introduction

One of the core studies to be conducted on all sites is a running estimate of lake physical and biological characteristics including some study of invertebrate communities. The protocol to be used among sites as to the periodicity of such observations has not been finalized. The major question is whether to sample on a seasonal basis, specifically in early spring during spring runoff, middle summer, and late fall, with a partial survey conducted during mid-winter; or to conduct intensive surveys during the period of maximum change. This year survey studies were conducted on three lakes: Central, Wallace, and Noname. A partial display of the results is shown in Figs 2 & 3. The data sets are most complete for Wallace. Some data, notably lake chemistry, are not shown in detail since the limited data set does not reveal anything not already shown by the lake temperature data and stream chemistry at the lake outflow.

Based upon the experience gained this past year we will attempt five sampling dates during 1984 in the following lakes: Wallace, Sumner, and Trout.

### Methods

Two stations were sampled on each lake. These were located along the long axis of the lake at one-third intervals. Four depths were sampled at each station (0.5, 1, 2, and 2.5 or 3 meters).

Temperature and light attenuation were measured with a lowered thermometer and photocell. A two-liter van Dorn bottle was used to collect water and plankton samples. Specific conductance (Beckman Conductimeter), alkalinity, and pH (Corning Portable), were determined within 12 hours of sample collection. A 60-ml subsample was filtered (0.45  $\mu$ m) and later analyzed for major ion species on an automated Dionex Model 10 Ion Chromatograph. An additional 500-ml was preserved with Lugol's solution and retained for plankton analysis.

Primary production was measured by the  $^{14}$ C Carbon method as outlined by Wetzel and Likens (1979). Samples were placed in 130-ml glass Dissolved Oxygen bottles and inoculated with 1-ml of  $5\mu\text{Ci NaH}^{14}\text{CO}_3$  from premeasured ampoules using a variable volume repeatable syringe. Two light and

one dark bottle were suspended horizontally beneath two separated floats and incubated for 4 hours between 1100 and 1500 hours. After incubation, aliquots from each bottle were filtered through 47 mm Nucleopore (0.45 $\mu$ m) filters at less than 380 mm Hg. Filters were folded into Whatman Qualitative filters and sealed in Whirl-paks for travel. Samples were dessicated for six hours, fumed with HCl for 10 minutes, and dessicated for an additional 4 hours. Activity was determined with a Packard Liquid Scintillation Spectrometer at Michigan Technological University. Carbon assimilation was determined according to Wetzel and Likens (1979).

Chlorophyll a was determined spectrophotometrically as outlined in Standard Methods (1980) and modified for DMSO extraction per Burninson (1979). For this 305-ml subsamples from each depth were filtered through 47mm Gelman Acetate filters (0.45 $\mu$ m) at less than 380 mm Hg vacuum. Filters were folded into Whatman Qualitative filters and stored frozen (<30 days) in Whirl-pacs until analysis. The acetate filters were dissolved in 4-ml of reagent grade dimethyl sulfoxide (DMSO) and heated in a 65° C hot water bath for 10 minutes. Samples were diluted to 10-ml with 90% acetone, agitated on a Vortex Mixer, and centrifuged for 10 minutes. The supernatant was measured and read on a Beckman Spectrophotometer at 750, 665, and 663 nm. To this 30 $\mu$ l of 4N HCl were added and the samples were re-read to correct for over-estimation due to phaeophyton. Chlorophyll a and Phaeophyton a were calculated by Lorenzen's (1967) spectrophotometric equations.

## Results

Partial experimental results are shown in Figs. 2 & 3. Alkalinity (mg CaCO<sub>3</sub>/l) in Central Lake (and Trout Lake) is less than one-half that generally observed in Wallace which in turn is less than Sumner. Mean values are 6.5, 19.5, and 34.6 mg/l respectively for the last year. Light attenuation with depth in Central and Trout is much less rapid than in Wallace (west and east stations). This apparently is due to a suspended colloidal layer at the lower depths of Wallace. This is supported by the data taken at the western station (W) which is an area of considerable organic matter accumulation.

As is readily apparent all these lakes are quite shallow which, with some notable exceptions, is characteristic of the region. Thermal stratification does not exist except possibly during a short period in spring. For a lake such as Wallace surface temperatures are up somewhat on a summer

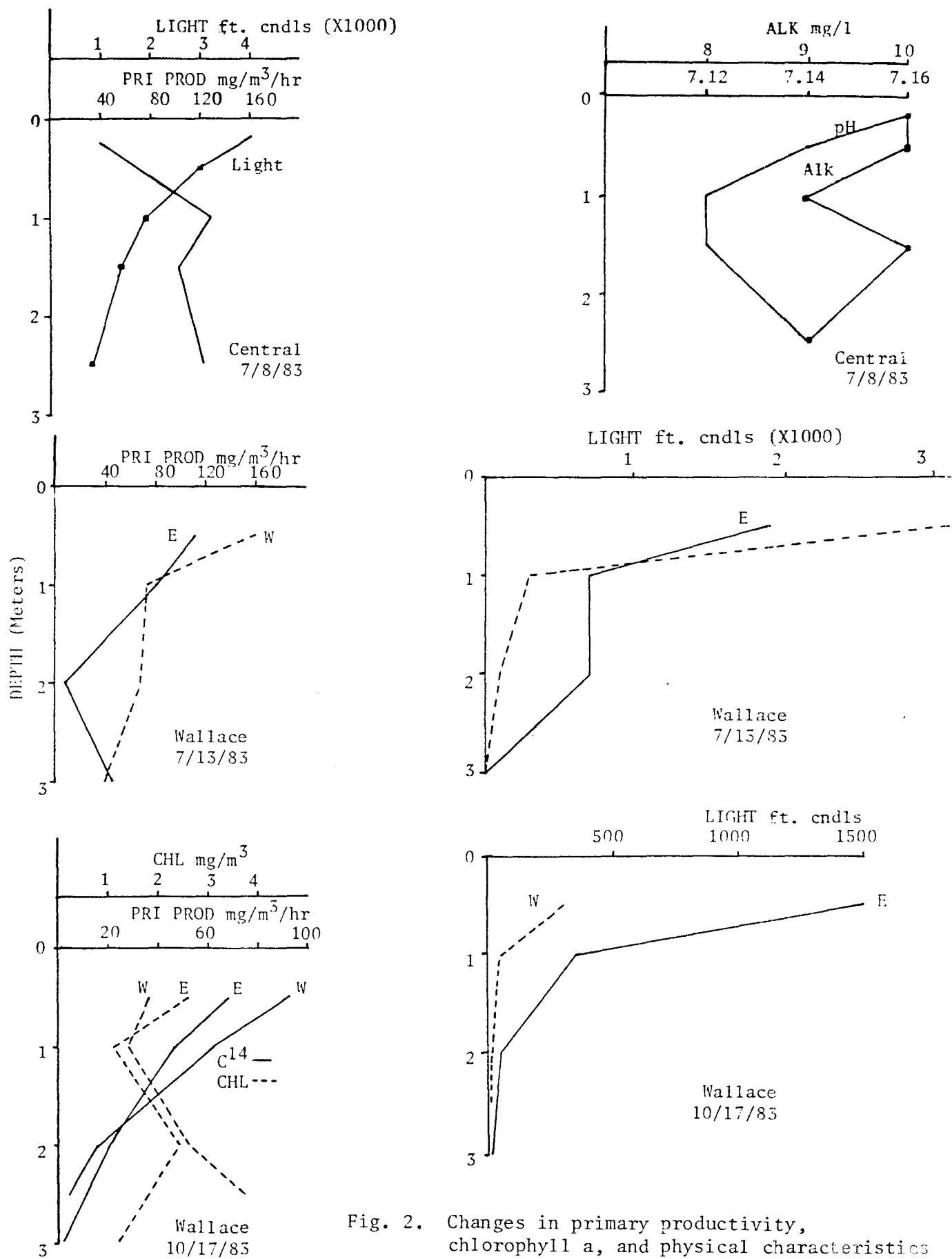


Fig. 2. Changes in primary productivity, chlorophyll a, and physical characteristics with increasing depth, Wallace and Central Lakes.

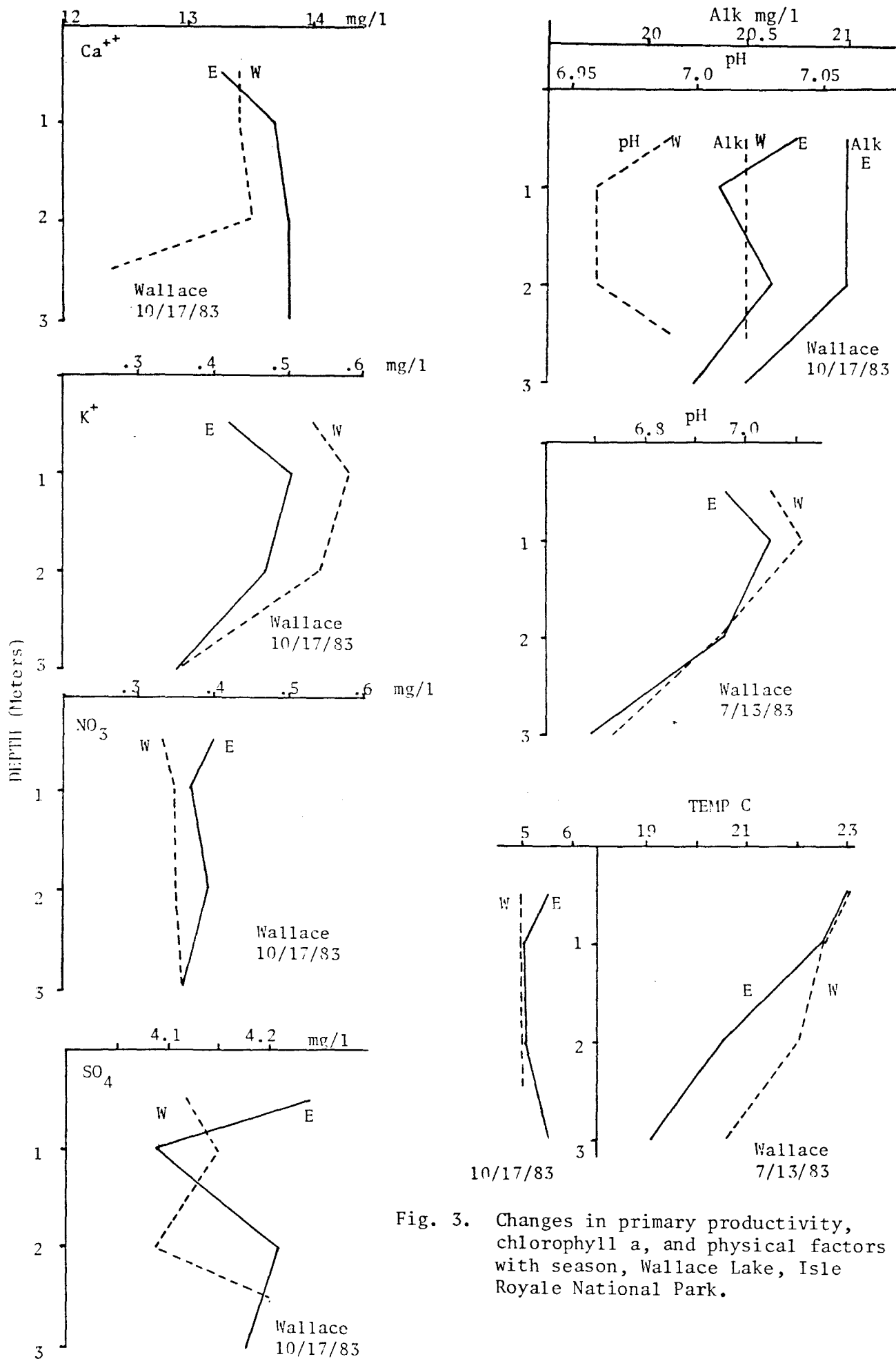


Fig. 3. Changes in primary productivity, chlorophyll a, and physical factors with season, Wallace Lake, Isle Royale National Park.

day, but not nearly as pronounced as one would find in a deeper lake. Little or no variation was noted with depth in fall or in winter.

Primary production near the surface (0.5m) is about 4x higher in Wallace compared to Central in early summer. However, little difference can be seen at 1.0m, and at greater depths Wallace declines significantly. This is probably due to the light limitation imposed by colloidal absorption. In late fall primary productivity has fallen somewhat, but generally is as high as seen during middle summer. By fall light intensities have been reduced to about one-half summer values due to the latitude of the region.

Mineral nutrient concentrations show very little change with depth. The only exception could be potassium which, on a percentage basis, is much lower in concentration near the surface and bottom. The cause of this is not clear with the present data set. Winter samples have been taken and are in the process of being analyzed. Sulfate shows considerable variation with depth which could be related to the levels of organic material present and its decomposition.

Productivity values for Wallace during the summer are slightly below those observed by Schindler and Nighswander (1970) from weekly sampling in a clear precambrian shield lake over the ice-free season. In October our values were approximately one-half the average noted by Schindler and Nighswander. Their samples were incubated, and our data set can not be directly compared at this time with their more intensive data set. Our values fall within the lower one-half of those ranges observed in the Experimental Lakes Area in southwestern Ontario (Schindler and Holmgren 1971).

## ANION MOBILITY IN FOREST SOILS

### Introduction

In boreal ecosystems, the potential exists for inputs of  $H^+$ , sulfate, and nitrate ions to affect forest productivity. This occurs as these ions enter the soil and chemically alter the soil solution. The net effect can be nutrient leaching from the rooting zone and mobilizing toxic concentrations of such elements as aluminum. Studies have been conducted to assess the effect of acids on forest soils with particular emphasis on nutrient cycling and cation leaching (Abrahamsen 1980, Alexander 1980, Cronan et al 1978, Norton et al 1977). In soils deficient in sulfur or nitrogen, increases in forest productivity may occur (Jonsson and Sundberg 1972, Cowling and Dochinger 1980).

The research presently underway on Isle Royale is particularly appropriate as there is little information on the effects of acid deposition and forest soils for the upper Great lakes region (Fish & Wildlife Service 1982, Westman 1980). Only within the last few years have some forest soils in the upper Great Lakes region been classified as sensitive based on surface soil characteristics (McFee 1981). Such soil parameters as cation exchange capacity, pH, % organic matter, cation/anion adsorption capacity and others have been used as criteria to identify those soils which may prove to vulnerable to acid deposition.

A theory which is applicable to soil nutrient cycling/leaching studies is that of anion mobility (Johnson and Cole 1977). Since chemical charge balance must be maintained in forest soils at all times, the occurrence of nutrient ion leaching can be determined by examining anion flux alone. In this region the sulfate/nitrate ratio in atmospheric deposition suggests that sulfate is the anion which most likely could result in cation nutrient leaching. Work done by Johnson and Cole (1977, 1980), Gebhardt and Coleman (1974), Chao et al (1964), and others suggest that sulfate adsorption in soils is enhanced by concentrations of aluminum and iron which favor adsorption kinetics, and low organic matter content. Artificial acidification experiments (Overrein & Seip 1980) have shown that acid rain at pH 4 or above is inefficient at replacing nutrient cations from podzolic soils characteristic of this region. As soil pH increases above 5 base cations are more effectively replaced by acidic inputs. The majority of

In boreal ecosystems, the potential exists for inputs of  $H^+$ , sulfate, and nitrate ions to affect forest productivity. This occurs as these ions enter the soil and chemically alter the soil solution. The net effect can be nutrient leaching from the rooting zone and mobilizing toxic concentrations of such elements as aluminum. Studies have been conducted to assess the effect of acids on forest soils with particular emphasis on nutrient cycling and cation leaching (Abrahamsen 1980, Alexander 1980, Cronan et al 1978, Norton et al 1977). In soils deficient in sulfur or nitrogen, increases in forest productivity may occur (Jonsson and Sundberg 1972, Cowling and Dochinger 1980).

The research presently underway on Isle Royale is particularly appropriate as there is little information on the effects of acid deposition and forest soils for the upper Great lakes region (Fish & Wildlife Service 1982, Westman 1980). Only within the last few years have some forest soils in the upper Great Lakes region been classified as sensitive based on surface soil characteristics (McFee 1981). Such soil parameters as cation exchange capacity, pH, % organic matter, cation/anion adsorption capacity and others have been used as criteria to identify those soils which may prove to vulnerable to acid deposition.

A theory which is applicable to soil nutrient cycling/leaching studies is that of anion mobility (Johnson and Cole 1977). Since chemical charge balance must be maintained in forest soils at all times, the occurrence of nutrient ion leaching can be determined by examining anion flux alone. In this region the sulfate/nitrate ratio in atmospheric deposition suggests that sulfate is the anion which most likely could result in cation nutrient leaching. Work done by Johnson and Cole (1977, 1980), Gebhardt and Coleman (1974), Chao et al (1964), and others suggest that sulfate adsorption in soils is enhanced by concentrations of aluminum and iron which favor adsorption kinetics, and low organic matter content. Artificial acidification experiments (Overrein & Seip 1980) have shown that acid rain at pH 4 or above is inefficient at replacing nutrient cations from podzolic soils characteristic of this region. As soil pH increases above 5 base cations are more effectively replaced by acidic inputs. The majority of

forest soils being investigated on Isle Royale range between pH 5.3 under spruce and 5.7 under northern hardwoods. It appears that less acid podzolic forest soils with low cation exchange capacity and developed on coarse siliceous material are relatively susceptible to acidification and nutrient leaching via anion mobility due to inputs of atmospheric sulfate and nitrate (Krug and Frink 1983). Precipitation and stream chemistry data collected on Isle Royale and the Keweenaw Peninsula show very little, if any, incorporation of  $\text{SO}_4$  in the ecosystem, and  $\text{NO}_3$  discharge from boreal ecosystems generally exceeds that observed in northern hardwood systems.

In general, the effects of anthropogenic inputs of acid sulfate and nitrate must be evaluated on the basis of internal nutrient cycling. Sulfate and nitrate ions must be mobile in the soil to facilitate leaching due to the requirement for charge balance. Net nutrient losses will only occur if leaching losses are greater than nutrient replacement from deposition and mineral weathering. Soil sensitivity is commensurate with moderate pH values, low concentrations of Al and Fe, low organic matter content, and inputs of N and S in amounts exceeding the requirements for vigorous growth.

### Hypotheses

1. Ecosystem input/output ratios for  $\text{NO}_3$  and  $\text{SO}_4$  are lower in boreal forested ecosystems than northern hardwood ecosystems on Isle Royale.
2. In ecosystems where coniferous species are more dominant, such as boreal systems, the preferential utilization of high-energy  $\text{NH}_4$  opens the possibility of some seasonal leaching losses due to  $\text{NO}_3$  mobility.
3. The high inputs of  $\text{NH}_4$ ,  $\text{NO}_3$ , Ca, Mg, and K due to fertilizer use, urban sources, and accompanied with dust from disturbed lands in the upper Midwest and Great Plains, further decreases the need in the boreal ecosystem for  $\text{NO}_3$  and increases the potential for nutrient leaching and/or ionic re-equilibrium due to this anion.

### Methods

Soil plots were established in two of the watersheds being studied on Isle Royale and in the Calumet watershed located on the Keweenaw Peninsula. Initial site evaluations for plot selection were accomplished in June 1983. The primary criteria used was forest type and percent organic matter in

the soil. Soil cores were taken at each perspective plot and percent organic matter was determined by drying at 95 degrees C for 24 hours or until no further weight loss was recorded. Initial sample weight was approximately 50 gr. The samples were then ashed at 550 degrees C for 8 hours, cooled in a dessicator and weighed again for loss on ignition.

Soil horizons were measured and recorded to depths ranging from 40 to 70 centimeters with the minimum depth at least 20 centimeters into the B horizon. Two of the plots are located in the Wallace Lake watershed. One is within a pure spruce stand and the other is located in a white birch-aspen stand. The percent organic matter and pH values are approximately 18-20% OM and pH 5.3 for the spruce plot. The birch-aspen plot is 12-14% OM and pH 5.5. Percent OM was determined on volume-weighted composite samples of the profile into the B horizon. A hardwood plot was established within the Washington Creek watershed following the same procedure. On the Keweenaw Peninsula a site was established in the Central Lake watershed in July 1983. In September 1983, after one month of data had been collected it was learned that a logging operation was to be initiated in the fall. The magnitude of the disturbance was sufficient to warrant abandonment of the soil plot. The present site is located in the Calumet stream watershed as previously noted. The Isle Royale and Calumet sites were selected in watersheds where a data base for precipitation and stream water chemistry currently exists.

On each plot lysimeters and throughfall collectors were located using a simple random grid design (Black 1965, Cochran 1953). Within each plot the following samples are taken: throughfall, litter leachate, and soil moisture in each horizon. The throughfall sampling equipment consists of ten 20 cm dia. rain collectors with funnel, filter and holding bucket. The rain collectors were placed in a design resembling the letter "H". Four snow buckets for precipitation collection during the months of November through April have been installed at each site. The Isle Royale sites will be sampled only twice during winter, but regularly throughout the winter at the Calumet site. For litter layer leachate, zero-tension lysimeters were constructed from a 15x25x5 cm tray connected to a tube and 500 ml collection bottle. "NYTEX" netting is secured over each collector to eliminate debris and clogging. Three such collectors are located in each plot. The zero-tension

lysimeters were installed by cutting a rectangular hole slightly larger than the collector with a trench and pit dug to receive the tubing and collection bottle. Sampling the soil solution within the profile is accomplished using porous-cup tension lysimeters manufactured by Soil Moisture Co. The lysimeters are about 5cm dia. and in lengths of about 25, 45, and 70cm(three samplers per depth within each site). The lysimeters were installed using a standard soil auger of a diameter slightly larger than the samplers to minimize disturbance of the soil column. Lysimeters of this type have been widely used in the study of soil water and ion transfer through forest soils (Cole 1968, Cole et al 1961, Haberland and Wilde 1961, Walliham 1960). The lysimeters were placed approximately 1 meter apart both within and between depths.

Initially sampling was performed biweekly; however, due to the very dry summer conditions, soil solution samples were very irregular and small through most of July and August. Now sampling will be performed on a monthly basis except during spring run-off when weekly samples will be collected at the Calumet site and biweekly on Isle Royale.

The data presented in the following section represent the first complete sample set which was collected during the fall together with summer and fall data which may be of some qualitative interest for comparison purposes. Throughfall samples were first measured for amount collected in each bucket. Then a 125ml subsample is saved for determination of pH and conductivity. Upon determination of pH and conductivity, a volume-weighted composite sample is filtered through a 0.4 $\mu$  filter for subsequent chemical analysis. The tension lysimeters are sampled using a hand pump connected to a liquid trap. Tension is applied for 12 to 24 hours at 15mm Hg prior to attempts at sample collection. Volumes vary appreciably but 125ml is collected if available.

pH and specific conductance are determined within 12 hours after sample collection. A subsample is then filtered and stored in a 60ml dark plastic bottle under refrigeration until analysis on an ion chromatograph. Aluminum determination is performed on an AA following acidification with HCl and addition of KCl to enhance detection (Standard Methods 15th ed. 1980). Silica is determined colorimetrically with absorption measured at 420nm (Standard Methods 15th ed. 1980).

In addition, basic soil properties will be described during the 1984 field season. Determinations of CEC, base

saturation, textural composition, percent organic matter, color(using current SCS terminology) and pH will be performed on a horizon by horizon basis to provide a complete soil description for each plot. Percent base saturation, cation exchange capacity, and extractable cations will be determined using standard LiCl and KCl extraction methods. LiCl will probably be used as this extraction method has been found best when analyzing extracted species on an IC. Air-dried soil samples and deionized water will be mixed into a 1:1 paste for determination of soil pH.

## Results

Preliminary results are presented in Table 3. The data were collected in October 1983 and represent the first complete data set for all of the soil plots. Prior sample sets are incomplete due to lack of sample at depth within a site or inconsistent samples at depth among the different sites. The values in Table 3 are mean values expressed in milliequivalents. Horizons represented are indicated by: LT=litter layer; A1/A2 and A2/B= horizon boundaries; B is within the horizon proper. Missing data is indicated by "-99.99" and "\*" indicates means were calculated using data of questionable reliability due to extremes in individual sample variation.

Figure 4 shows the relationship between Al and pH of the soil solution with depth. In all three plots, aluminum concentration in the soil solution increases as moisture passes through the litter layer, A 1 and A 2 horizons. Some changes in concentration occur at the A2/B boundary and in the B horizon where Al appears to increase. Additional lysimeters will be placed at greater depths at the B/C horizon interface to provide a more complete description of the behavior of aluminum, as well as other ions, in solution.

While it is premature to attempt to predict what the behavior of aluminum in these soils is at present, the trend of increasing concentration through the A2 is consistent with the results obtained by Cronan and Schofield (1979) studying podzolic soils of the White Mountain and Adirondack Mountain regions in the northeastern United States. The relationship between aluminum and soil solution pH is not clear at the present time, but is probably multifactorial in nature.

Table 4 describes precipitation vs. throughfall quality for August through mid-October 1983 for the Wallace site. In all cases precipitation pH increases as it passes through

TABLE 3. Mean Values For Major Ion Species  
On Isle Royale (expressed in meq)

| WINDIGO           | WALLACE EAST    | WALLACE WEST    |
|-------------------|-----------------|-----------------|
| mean (st. dev.)   | mean (st. dev.) | mean (st. dev.) |
| Calcium           |                 |                 |
| LT 203.0(79.76)   | 271.96(92.79)   | 534.65(161.71)  |
| O/A 76.14(71.06)  | 311.09(53.37)   | 994.43(153.59)  |
| A/B 186.17(20.61) | 191.37(129.71)  | 252.26(105.42)  |
| B 205.56(26.81)   | 287.76(36.54)   | 263.74(32.60)   |
| Magnesium         |                 |                 |
| LT 47.02(14.83)   | 42.49(29.37)    | 96.89(19.20)    |
| O/A 22.83(25.36)  | 19.24(9.16)     | 406.61(196.84)  |
| A/B 69.93(2.75)   | 80.28(53.05)    | 112.07(79.16)   |
| B 78.06(2.14)     | 132.17(19.83)   | 97.92(29.42)    |
| Sodium            |                 |                 |
| LT 3.35(0.62)     | 0.23(0.18)      | 2.07(1.15)      |
| O/A 19.71(11.99)  | 19.24(9.16)     | 92.62(58.47)    |
| A/B 23.95(14.75)  | 87.95(50.91)    | 104.96(54.61)   |
| B 37.69(8.71)     | 61.22(12.58)    | 74.24(32.45)    |
| Potassium         |                 |                 |
| LT 89.93(40.18)   | 121.52(77.39)   | 98.97(22.10)    |
| O/A 9.13(4.22)    | 46.44(22.10)    | 65.63(65.26)    |
| A/B 8.71(2.74)    | 7.01(9.72)      | 12.64(5.66)     |
| B 7.87(1.24)      | 1.72(0.56)      | 8.18(6.46)      |
| Ammonium          |                 |                 |
| LT ca. 0          | 17.67(14.89)    | 20.84(11.62)    |
| O/A ca. 0         | 0.46(0.41)      | 3.41(5.92)      |
| A/B ca. 0         | ca.50(ca.70)*   | 4.28(4.13)      |
| B ca. 0           | 0.49(0.20)      | 3.10(4.79)      |
| Sulfate           |                 |                 |
| LT 53.34(11.29)   | 52.14(6.05)     | 79.25(77.08)    |
| O/A -99.99        | 90.91(23.60)    | 337.33(183.19)  |
| A/B 136.92( )     | 84.40(48.81)    | 308.26(359.87)  |
| B 118.67(11.99)   | 169.78(30.45)   | 368.04( )       |
| Nitrate           |                 |                 |
| LT 27.50(30.01)   | 1.86(3.22)*     | 0.23(0.30)      |
| O/A ca. 0         | ca. 0           | 0.56(0.49)      |
| A/B 0.19(0.33)    | ca. 0           | 0.27(0.34)      |
| B ca. 0           | 0.90(1.56)      | ca. 0           |

TABLE 3 cont.  
WNDG

WSE

WSW

Aluminum

|    |                 |            |            |
|----|-----------------|------------|------------|
| LT | <2.75( )        | 7.32(0.17) | 4.23(0.33) |
|    | O/A 87.24(0.35) | 8.79(0.08) | 27.49(0.4) |
|    | A/B 3.71(0.04)  | <2.75( )   | 4.67(0.02) |
| B  | 5.14(0.02)      | 3.69(0.07) | <2.75( )   |

Silica

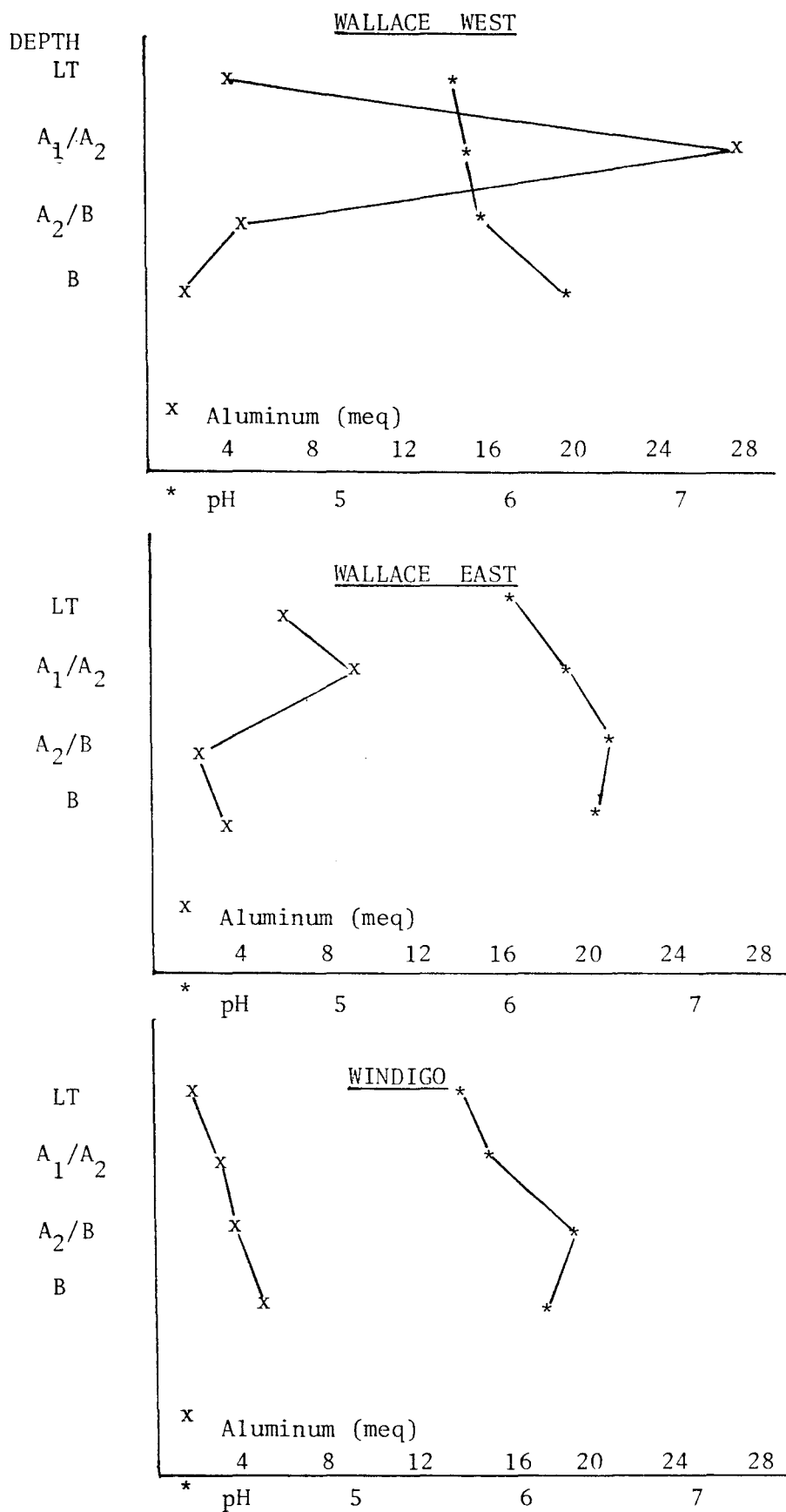
|     |           |          |           |
|-----|-----------|----------|-----------|
| LT  | 33.45( )  | 60.90( ) | 63.95( )  |
| O/A | 316.68( ) | 54.81( ) | 48.72( )  |
| A/B | 243.6( )  | 365.4( ) | 280.14( ) |
| B   | 179.52( ) | 130.9( ) | 140.07( ) |

TABLE 4. Incident Precipitation vs. Throughfall Quality (mg/L) for the period, August-October 1983.

| OPEN | WALLACE WEST | WALLACE EAST | OPEN*     | WINDIGO*       |
|------|--------------|--------------|-----------|----------------|
| Amt  | 32.72        | ca. 16.36    | ca. 16.36 | 13.49 ca. 6.75 |
| Ca   | 0.254        | 2.455        | 3.330     | 0.415 2.070    |
| Mg   | 0.043        | 0.604        | 0.932     | 0.045 0.388    |
| Na   | 0.237        | 0.874        | 0.925     | 0.365 0.422    |
| K    | 0.534        | 3.030        | 4.200     | 0.280 3.400    |
| NH4  | 0.355        | 1.565        | 0.325     | 0.080 ca.0     |
| NO2  | 0.280        | 0.002        | 0.004     | 0.005 0.001    |
| NO3  | 2.401        | 0.476        | 0.825     | 0.455 ca.0     |
| PO4  | 0.043        | 0.586        | 0.080     | ca.0 ca.0      |
| SO4  | 1.964        | 5.219        | 4.104     | 2.100 2.662    |
| Cl   | 0.376        | 1.720        | 1.360     | 0.400 0.573    |
| pH   | 4.29         | 5.99         | 6.05      | 4.26 5.72      |

\* Dates for the Windigo site are 9/23 and 10/19 1983. Precipitation amounts for throughfall data not presently available and are estimates based on average loss due to evapotranspiration.

FIG. 4. SOIL SOLUTION ALUMINUM vs. pH and DEPTH



the forest canopy. Two year's of data for equivalent sites on Isle Royale from March 1980-1982 show net increases in ion concentrations for all ions except  $\text{PO}_4$  which displayed a net decrease, albeit small. Throughfall data collected in the soil plots show a net increase for Ca, Mg, Na, K,  $\text{PO}_4$ ,  $\text{SO}_4$ , and Cl but net decreases for  $\text{NH}_4$ ,  $\text{NO}_2$  and  $\text{NO}_3$ , (and  $\text{PO}_4$  in the Windigo plot). The apparent inconsistencies for the present data are largely due to the small number of data points (five for Wallace and two for Windigo), and interference from understory vegetation intercepting some of the canopy throughfall in the Wallace East and Windigo sites during August and September.

## LITERATURE CITED

- Abrahamsen, G. 1980. Impact of sulfur deposition on forest ecosystems . In Atmospheric Sulfur: environmental impact and health effects. D. S. Shriner, C. R. Richmond, and S. E. Lindberg eds. Ann Arbor Science, Ann Arbor, Michigan. pp. 397-416.
- Adams, Charles C. 1909. An ecological survey of Isle Royale, Lake Superior. Wynkoop, Hallenbeck, Crawford Co., Lansing, MI. 468 p.
- Alexander, M. 1980. Effects of acid precipitation on biochemical activities in soil. In Ecological impacts of acid precipitation, D. Drablos and A. Tollan eds. The Nor. Interdisciplinary Research Programme, Acid Precipitation-Effects on Forest and Fish, Oslo, Norway.
- Baskerville, G. L. 1965. Dry matter production in immature balsam fir stands. For. Sci. Monograph 9:42 pp.
- Black, C. A., D. E. Evans, J. L. White, L. E. Ensminger and C. Clark eds. 1965. Methods of Soils Analysis, Part 1: Physical and Mineralogical Properties. American Soc. of Agron. 770 pp.
- Braun, E. Lucy. 1950. Deciduous forests of eastern north America. The Blakiston Company, Philadelphia, PA.
- Burnison, B. K. 1980. Modified dimethyl sulfoxide (DMSO) extraction for chlorophyll analysis of phytoplankton. Can. J. Fish. Aquat. Sci., 37:729-733.
- Chao, T. T., M. E. Harward, and C. S. Fang. 1964. Iron or aluminum coating in relation to sulfate sorption characteristics of soils. Proc. Soil Sci. Soc. Am. 38:259-262.
- Cochran, W. G. 1953. Sampling Techniques. John Wiley & Sons, NY.
- Cole, D. W., S. P. Gessel, E. E. Held. 1961. Tension Lysimeter studies of ion and moisture movement in glacial till and coral atoll soils. Soil Sci. Soc. Am. 25: 321-325.
- Cole, D. W. 1968. A system for measuring conductivity, acidity, and rate of water flow in a forest soil. Wtr. Res. Res. 4:1127-1136.

- Cooper, W. S. 1911. The climax forest of Isle Royale, Lake Superior, and its development. Dissertation (unpub.), Univ. Chicago. 44p.
- Cooper, W. S. 1912. The ecological succession of mosses, as illustrated upon Isle Royale. *Plant World* 15:197-213.
- Cooper, W. S. 1913. A list of mosses collected on Isle Royale, Lake Superior. *Bryologist* 16:3-8.
- Cowling, E. B., and L. S. Dochinger. 1980. Effects of acid precipitation on health and productivity of forests. U.S.D.A. For. Serv. Gen. Tech. Rep. PSW-43, 165-173.
- Cronan, C. S., W. A. Reiners, R. L. Reynolds, and G. E. Lang. 1978. Forest floor leaching: contributions from mineral, organic and carbonic acids in New Hampshire subalpine forests. *Science* 200:309-311.
- Doucet, R., J. V. Berglund, and C. E. Farnsworth. 1976. Dry matter production in 40-year *Pinus banksiana* stands in Quebec. *Can. J. For. Res.* 6(3):357-367.
- Dyer, F. R. 1967. Fresh and dry weight, nutrient elements and pulping characteristics of northern white cedar *Thuja occidentalis*. School of Forestry, Univ. of Maine. Maine Agr. Exp. Sta. Tech. Bull. 27: 40 p.
- Fish and Wildlife Service. 1982. The effects of air pollution and acid rain on fish, wildlife, and their habitats: forests. FWS/OBS-80/4016 Air Pollution and Acid Rain, Report No. 6, June 1982.
- Gebhardt, H., and N. T. Coleman. 1974. Anion sorption by allophanic tropical soils 11: sulfate adsorption. *Proc. Soil Sci. Soc. Am.* 38:259-262.
- Haberland, F. P. and S. A. Wilde. 1961. Influence of thinning of red pine plantations on soil. *Ecology* 42:584-586.
- Hegyi, F. 1972. Dry matter distribution in jack pine stands in northern Ontario. Repr. from *The For. Chron.* 48(4):5 pp.
- Huber, N. King. 1975. The geologic story of Isle Royale National Park. *Geological Survey Bulletin* 1309. 66 p.

- Janke, R. A. 1976. Moose-boreal forest ecology in Isle Royale National Park. Proc. of the 12th North American Moose Conf. and Workshop, St. Johns, Newfoundland, March, 1976. pp. 70-90.
- Janke, R. A. Annual Progress Reports to the U.S. National Park Service, 1977-1983.
- Johnson, D. W., and D. W. Cole. 1977. Anion mobility in soils; relevance to nutrient transport from terrestrial to aquatic systems. U.S.E.P.A. ERL, Corvallis, OR. EPA-600/3-77-068. June 1977.
- Johnson, D. W., J. Turner and J. M. Kelly. 1982. The effects of acid rain on forest nutrient status. Wtr. Res. Res. 18(8):449-461.
- Jonsson, B. and R. Sundberg. 1972. Has the acidification by atmospheric pollution caused a growth reduction in Swedish forests? Rep. 20, Dept. of Forest Yield Res., College of Forestry, Stockholm, Swed., in: Johnson, D. W., J. Turner and J. M. Kelly, 1982.
- Krefting, L. W. 1974. The ecology of the Isle Royale moose with special reference to the habitat. Minn. Ag. Expt. Sta. Tech. Bull. No. 297, 76 p.
- Krug, E. C. and C. R. Frink. 1983. Acid rain on acid soil: a new perspective. Science 221:520-525.
- Kurucz, J. 1969. Component weights of Douglas-fir, western hemlock and western red cedar biomass for simulation of amount and distribution of forest fuels. MF Thesis, The Univ. of British Columbia, Vancouver, B.C. Faculty of Forestry:116 pp.
- Larsen, James A. 1980. The boreal ecosystem. Academic Press, New York, NY. 500 p.
- Linn, Robert M. 1957. The spruce-fir, maple-birch transition in Isle Royale National Park, Lake Superior. Unpub. PhD Thesis, Duke Univ., Durham, NC.
- Linn, Robert M., Lowell Sumner, and George Sprugel, Jr. 1966. Isle Royale National Park Natural Sciences Research Plan. U.S. Dept. of Interior, National Park Service, Washington, D.C.
- Lorenzen, C. J. 1967. Determination of chlorophyll and phaeo-pigments: spectrophotometric equations. Limnol. Oceanogr. 12:343-346.

Maycock, Paul F. 1961. The spruce-fir forests of the Keweenaw Peninsula, northern Michigan. Ecology 42(2): 357-365.

McFee, W. W. and C. S. Cronan. 1981. The action of wet and dry deposition components of acid precipitation on litter and soil. MSU Institute of Water Res. Initial Draft Proc. Eff. Ac. Prec. on Ecol. Systems: Great Lakes Region. 1981 April 1-3, MSU, East Lansing, MI.

Moir, W. H., and R. Francis. 1972. Foliage biomass and surface area in three *Pinus contorta* plots in Colorado. For. Sci. 18:41-45.

NADP. 1982. Distribution of surface waters sensitive to acidic precipitation: a state level atlas. NADP Tech. Rept. No. IV, S. A. Norton (ed). 72 p.

Overrein, L. N. and H. M. Seid. 1980. Acid precipitation-effects on forests and fish. Final Report of SNSF Proj. 1972-1980. Oslo-As, Nor. 175 p.

Peterson, R. O. 1977. Wolf ecology and prey relationships on Isle Royale. NPS Sci. Monog. No. 11, 210 p. GPO Washington, D.C.

Peterson, E. B., Y. H. Chan and J. B. Cragg. 1970. Above-ground standing crop, leaf area, and caloric value in an aspen clone near Calgary, Alberta. Can. For. Serv. Calgary, Alberta. Can. J. Bot. 48:1459-1469.

Ribe, J. H. 1973. Puckerbrush weight tables. Life Sci. and Agri. Exp. Sta., Univ. of Maine at Orono. Misc. Rep. 152:92 pp.

Schindler, D. W., and S. K. Holmgren. 1971. Primary production and phytoplankton in the Experimental Lakes Area, northwestern Ontario, and other low-carbonate waters, and a liquid scintillation method for determining  $^{14}\text{C}$  activity in photosynthesis. J. Fish. Res. Bd. Canada 28:189-201.

Schindler, D. W., and J. E. Nighswander. 1970. Nutrient supply and primary production in Clear Lake, eastern Ontario. J. Fish. Bd. Canada 27:2009-2036.

Shelford, Victor E. 1963. The ecology of North America. University of Illinois Press, Urbana, Ill. 610 p.

Siccama, T. G., F. H. Bormann, and G. E. Likens. 1970. The Hubbard Brook Ecosystem Study: productivity, nutrients and phytosociology of the herbaceous layer. Ecol. Monogr. 40(4):373-388.

Standard Methods of Water and Wastewater Analysis 1982. 15th edition.

Stanek, W., and D. State. 1978. Equations predicting primary productivity (biomass) of trees, shrubs and lesser vegetation based on current literature. Can. For. Serv., Pacif. For. Res. Cent., No. BC-X-183, 58p.

Verry, E. S. 1983. Precipitation chemistry at the Marcell Experimental Forest in North Central Minnesota. Water Resour. Res. 19:454-462.

Walliham, E. F. 1960. An improvement in lysimeter design. J. Am. Soc. Agron. Eng'rs. 3:13-15, 18.

Westman, W. E. 1980. Remarks and summary of audience/panel discussion. P. R. Miller, ed. Proc. Symp. of Eff. of Air Pollution on Mediterranean and Temperate Forest Ecosystems. June 22-27, 1980, Riverside, CA. U.S.D.A. For. Serv. Pacific Southwest and Range Experiment Sta. Gen. Tech. Rep. PSW-43, 215-220.

Wetzel, R. G., and G. E. Likens. 1979. Limnological analyses. W. B. Saunders, Philadelphia, PA. 357p.

Whittaker, R. H., F. H. Bormann, G. E. Likens, T. G. Siccama. The Hubbard Brook Ecosystem Study: forest biomass and production. Ecol. Monogr. 44(2):233-254.

Young, H. E., L. Strand and R. Altenberger. 1964. Preliminary fresh and dry weight tables for seven tree species in Maine. Maine Agr. Exp. Sta., Orono, Maine. Tech. Bull. 12:76 pp.

STATUS OF CORE REQUIREMENTS AND OTHER MAJOR RESEARCH AREAS  
GREAT LAKES AREA RESOURCE STUDIES UNIT  
DECEMBER, 1983

ECOSYSTEM COMPONENT: PRECIPITATION

Core Requirements

- A. "Each site will have a NADP collector standardized with a bulk collector. NADP sample will be sent to NADP laboratory following established protocol."

Status: The Isle Royale sites are about 45 km from NADP station 232570 which has been paired with a bulk collector since August 1980. In addition, a bulk collector has been in operation at the Wallace Lake site since June 1981 and aerometers samplers will be installed at that site and the Trout Lake site in the spring of 1984. These new stations will not be part of the NADP system; however, collection and analysis will follow established NADP protocol. In all cases the bulk collection schedule follows exactly that of NADP.

- B. "Bulk samples will be sent to the laboratory used by the Isle Royale study (MTU) or equivalent facility for analysis of cations and anions including Ca, Mg, Na, K, acidity/alkalinity, Cl, SO<sub>4</sub>, and N (all species)."

Status: Bulk collector samples from the Isle Royale sites are analyzed for pH and conductivity at the Boreal Research Station within 12 hours of sample collection. The samples are transported on a weekly basis to the lab at MTU where they are analyzed for Ca, Mg, Na, K, Cl, SO<sub>4</sub>, NO<sub>2</sub>, and NO<sub>3</sub> on a Dionex ion chromatograph. All samples are refrigerated during storage and transport. Bulk sampling will be initiated at the Trout Lake site in early spring 1984 and analysis will also be conducted at the MTU lab.

- C. "Snowfall will be measured using a combination of snow boards and snow cores, or widemouth collectors, optionally on a weekly basis."

Status: Bulk snow collectors were in operation at the Wallace Lake site during winter 1982 and have again been installed at that site as well as the Trout Lake site for winter 1983. Since the Isle Royale stations are in such close proximity one collection station will

be sufficient for the two watersheds. Bulk collectors are 27 cm diameter plastic lined tubes. Additionally, snow will be collected in three widemouth plastic containers under a deciduous canopy and a coniferous canopy in the Wallace Lake watershed in conjunction with soil lysimeter sampling. Sampling at Trout Lake will be on a weekly basis and that at Isle Royale will be dependent on the limited winter access. Snow samples will be analyzed in a similar fashion to precipitation at the MTU lab.

D. "Q.A. will be established and reviewed by the U.S.G.S."

Status: Laboratory quality assurance presently consists of running standards every eight samples, splitting NADP samples from the Houghton station and comparing results to the CAL, periodically receiving from USGS and EPA stream samples of known chemistry for testing, routine analyses of outliers as determined by plots of conductance and total cations, and use of Bureau of Standards plant tissues.

E. "Selected trace metals such as Pb, Cd, Al will be included in the analysis as required."

Status: All watershed samples collected to date have been archived. It now appears that ICPE will prove adequate for the analyses of most trace metals of interest except for Zn and probably Al. The latter will be analyzed by AA or the samples will be concentrated for ICPE. Present plans call for the analysis of all stream and precipitation samples composited on a monthly basis.

Additional Activities:

None.

ECOSYSTEM COMPONENTS: SNOW PACK

A. No core requirements.

Status: Snow cores will be taken at the Isle Royale and Trout Lake sites during the winter of 1983-84 as they were during winter 1982-83 at the Isle Royale sites. Snow cores for qualitative analysis are collected using a PVC tube. Water content is determined using a Mt. Rose sampler. The Trout Lake site will be sampled on a weekly basis. Sampling frequency on Isle Royale varies during winter due to access limitations.

ECOSYSTEM COMPONENTS: THROUGHFALL/STEM FLOW

- A. No core requirements.

Status: Throughfall was collected at two plots in the Wallace Lake watershed during the summer of 1983. Sample collection was on a bimonthly basis in conjunction with sampling from tension lysimeters located in the same plots. One plot was located in a coniferous stand, the canopy primarily composed of white spruce and the second plot was under a deciduous canopy dominated by white birch.

A three-year all-season study of canopy throughfall and stemflow was just completed at three sites within a watershed on the southwest end of the park, 45 km from the watersheds we're studying.

ECOSYSTEM COMPONENTS: RADIATION/ATMOSPHERIC (CLIMATE)

Core requirements

- A. "Wind speed and direction, relative humidity, air temperature, soil temperature, insolation and precipitation will be recorded on site. A standardized method of data collection involving an automatic recording weather station and data logger, and a means by which data can be stored, retrieved, analyzed, and shared among study areas has been developed."

Status: The Wallace Lake site was equipped in fall 1982 with a recording precipitation gauge and a recording hygrothermograph housed in a standard weather station. The Wallace meteorological equipment will be replaced with a Campbell Scientific Meteorological Station in spring 1984. Again, due to the close proximity of the two Isle Royale watersheds one station will be sufficient for both sites. The station takes all measurements specified in the core requirements. The storage module is retrieved every eight weeks (or longer during summer) at the Isle Royale site. A remote area weather station or the equivalent will be installed at the Trout Lake site this year.

ECOSYSTEM COMPONENTS: OZONE/DRY DEPOSITION

- A. No core requirements. "Dry deposition measurement may be required after a standardized procedure is accepted."

ECOSYSTEM COMPONENT: SOILS

- A. "A one-time soil collection will be made to the "C" horizon at a minimum of two locations within each study watershed. Analysis to be performed on major soil and litter horizons will include total sulfur, phosphate (Bray method), Kjeldahl ammonia, nitrate nitrogen and total carbon. Total exchangeable and water soluble cations, cation exchange capacity, pH, bulk density, particle size by classes of less than 2 mm, and percent by volume of size classes greater than 2 mm (particle breakdown) will also be measured."

Status: Soil samples will be collected and analyzed in 1984.

- B. "Soils will be air dried and stored in whirl-pac bags for archival purposes in the central repository (C.S.U.)."

ECOSYSTEM COMPONENT: VEGETATION

Core requirements

- A. "A vegetation map will be developed for each watershed where such does not already exist. Permanent 0.1 ha vegetation plots will be established in each watershed. Plots will be selected in an unbiased manner to represent the vegetation/soil/slope/aspect/altitudinal variants of interest within the watershed. A minimum of 5 plots will be established for each selected variant in order to assume statistical validity. For each plot all trees will be mapped and a representative number permanently marked. Diameter at breast height (DBH) and height will be recorded for all trees where such is possible. A line intercept method will be used to record shrub species and cover. Herbaceous species will be recorded using a Braun-Blanquet type cover-abundance scale on a minimum of five 1 m systematically placed subplots."

Status: Vegetation maps have been developed for both Isle Royale watersheds using 1977 1:24,000 color aerial photos. It is anticipated that a vegetation map for the Trout Lake site will be completed this winter. Four 0.1 ha permanent vegetation plots were established in each of the Wallace Lake and Noname Lake watersheds. The plots will be added to the series of permanent vegetation plots already established in the park and marked accordingly. In each plot diameter at breast height (DBH) and total height was recorded for all tree

species (DBH > 2.5cm) in the canopy and understory. Increment cores were obtained from all trees with a DBH greater than 7cm in two 10 m x 12 m subplots in the larger plot. Saplings (DBH < 2.5cm, height > 0.5 m) were recorded as to species and height in a 2m x 5m subplot located in each of the four corners of the major plot and the same was done for seedlings (tree species < 0.5m tall) in 1m x 1m subplots nested in the sapling plots. A 50 m long transect was established in the center down the long axis of the plot along which five 1m subplots were established at predetermined locations. Herbaceous vascular plant cover was estimated for each non-tree species less than 0.5m in height in each of the five subplots. Coverage of taller herbs and shrubs all exceeding 0.5m in height was estimated in three 2m x 2m subplots which were nested outside three of the 1m subplots. A fifth permanent vegetation plot will be located in each of the two watersheds during summer 1984 and trees will be mapped in all the permanent plots at that time also. Due to its relatively late selection there was no opportunity for vegetation sampling in the Trout Lake watershed. This will be completed in summer 1984.

- B. "Dead wood on the ground will be measured by size class in order to estimate dry weight. Litter and duff will be measured by depth and correlations established with dry weight."

Status: A transect was established down the long axis of each permanent vegetation plot and the diameter of all windfalls intercepted by the transect was measured at breast height and at two meter intervals down the bole. Total length was also measured. Additionally, recent windfalls for all major tree species in the Wallace Lake watershed were located throughout the watershed and these same measurements were taken. From this data volume tables specific to Isle Royale will be constructed and compared to the existing published volume tables for the Upper Great Lakes Region. If the comparison is good, published tables will be used for calculating standing biomass.

- C. "Permanent photopoints will be established for each plot."

Status: Permanent photopoints will be established for the new vegetation plots during summer 1984.

- D. "Qualitative phenology observations of branch elongation, leaf initiation and expansion, flowering, fruiting, fruit dissemination and leaf fall will be recorded for dominant species on a regular basis through the growing season."

Status: This will be initiated in 1984 for the major species found in the watersheds during the plot surveys of 1983-84.

- E. "Permanent plots will be re-read every five years."

Status: Five years is the stated period for a permanent plot survey update, however, this will probably be found somewhat too frequent in low-productivity areas such as the boreal forested regions of the Upper Great Lakes.

#### Additional Activities:

- F. In addition to estimating percent cover for all species of herbaceous vascular plants and shrubs, considerable effort has been put forth to quantify biomass in the Wallace Lake and Noname Lake watersheds. Stem counts were obtained for all species except grasses and sedges in the five  $\text{lm}^2$  subplots of the permanent vegetation plots. The current growth of herbs and shrubs was clipped and bagged by species. Oven dry weights were obtained for all species and nutrient analysis of the tissue samples has been completed on the ion chromatograph for those species which contributed significantly to total biomass of the plots. Published biomass equations have been used to determine standing biomass of trees by species for the 2 watersheds. Similar sampling will be conducted at Trout Lake next summer.

#### ECOSYSTEM COMPONENT: LITTER AND DUFF

##### Core Requirement

- A. "Qualitative information on the development of humus layers and chemical analysis of major litter horizons will be collected every five years."

Status: Leaf fall data collection was initiated in fall 1983 with the systematic placement of six  $\text{lm}^2$  leaf traps in one of the permanent vegetation plots in the Wallace watershed. The canopy is primarily deciduous (birch) in this particular vegetation plot. Also fresh fallen white birch leaves were collected

and dried, then bound with monofilament in 10 gram subsamples. Each 10 gram litter pack was subsequently attached to a rock and 3 groups of 10 litter packs were placed in the stream outflow from Wallace Lake. Collection of the litter packs will be on a monthly basis beginning in April 1984. Upon collection invertebrates will be removed from each litter pack and identified and the litter will be analyzed for dry weight, and nutrient content of major cations and anions will be run on the ion chromatograph. The experiment has been set-up in triplicate to facilitate statistical analysis.

A standard mesh-bag litter decomposition study has previously been completed at three terrestrial sites and in two streams in the park. Results of this previous study are thought applicable to the two watersheds we're studying.

#### ECOSYSTEM COMPONENT: AQUATICS

##### Core Requirements

- A. "General qualitative information on streams will include; stream topography, soil parent material, soil type, vegetation cover, land use and human impact, channel gradient, discharge records, and major channel woody debris, sediment distribution and composition, and a riparian vegetation survey."

Status: Emphasis will be placed on the aquatic component of the three watersheds under study starting in spring 1984. Monitoring of stream discharge has been underway for some time now and is explained more fully under core requirement D of this aquatic section. Collection of general qualitative information on stream topography, soil parent material, soil type, vegetation cover, land use and human impact, channel gradient, major channel woody debris, sediment distribution and composition will be completed during summer 1984. A riparian vegetation survey will also be completed for the three watersheds.

- B. "Qualitative information on lakes will include a bathymetric map, shore and bottom characterization, sources of water, thermal characteristics, trophic type and relationship to topography, soil parent material, soil type, vegetation cover, land use and pollution."

Status: Qualitative information on lakes will be completed during 1984.

- C. "Qualitative information on wetlands includes a topographic survey of mineral soil surface and peat surface and of spring (high) and late summer (low) water table and a vegetation survey."

Status: Qualitative information on wetlands has not been collected to date, however, a strategy for doing this type of sampling will be developed in spring of 1984.

- D. "Weekly stream temperature range will be recorded for a minimum of one year. Stream discharge will be continuously recorded at appropriate locations for basin input/output analysis."

Status: Monitoring of stream discharge was initiated in 1982 at Wallace Lake with the installation of a parshall flume and Stevens Stage Height Recorder at the outflow. In spring 1983 a stage height recorder and V-notch weir were installed at the inflow to that lake as well as a stage height recorder at the outflow from Sumner Lake. Stream discharge will be monitored at Trout Lake beginning in spring 1984. Stream temperatures are taken at all sites in conjunction with routine weekly sampling and continuous recording pH and temperature meters will be installed at the lower stations of the three watersheds in spring 1984.

- E. "Stream water samples will be collected on a weekly basis except during times of rapidly changing discharge (spring snow melt, summer precipitation events) when samples will be collected over the rising and falling limbs of the hygrograph. Chemical mass balances for the major cations and anions will be calculated from input and output data. The relationships between stream discharge and nutrient concentration will be calculated on an annual basis to examine overall ecosystem functioning and response to disturbance for representative ions. Ecosystem nutrient budgets will be calculated from input/output data."

Status: Stream samples were collected on a weekly basis at the Isle Royale sites from early May until mid-October 1983 at which time all personnel returned to the main-

land. At that time a Manning Auto Sampler was installed at the Wallace Lake site and programmed to take stream samples on a weekly basis. This sampler has the potential to collect samples for an additional 12 weeks and the samples will be collected when the site is visited in January during the winter study. Normal sample processing includes measurements of pH conductivity, and alkalinity performed within 12 hours of sample collection at the Boreal Research Station and weekly transport of samples to the lab at MTU where they are analyzed for major cations and anions on the ion chromatograph. Processing of those samples obtained from the Manning Auto Sampler is the same except that pH and alkalinity will not be measured due to the excessive time elapsed between sample collection and processing. These data will subsequently be used in the calculation of ecosystem nutrient budgets. This routine sampling will again resume when personnel return to the island in spring 1984 and a similar sampling regime at the Trout Lake site will begin at that time following identical collection and analysis procedures.

Sampling will be conducted much more frequently during periods of spring snow melt and summer precipitation events. The Manning Auto Samplers have been and will continue to be operated during these periods of rapidly changing discharge. Sampling with the Manning Auto Samplers will further be improved with the addition of stage height sensors.

- F. "The importance of groundwater flow will be assessed."

Status: To conduct such a study on these sites will be difficult due to the numerous wetlands separated by exposed bedrock. It is doubtful that any significant groundwater connections exist for these lakes due to the shallow depth to bedrock. This topic will be addressed at the spring 1984 meeting.

- G. "Lake water samples will be collected once during mid-winter ice cover, at the time of maximum spring discharge into the lake, immediately after ice melt, and during summer stratification, and at fall turnover. Integrated water samples will be collected when thermal stratification is absent. At times of lake stratification samples will be collected from the epilimnion, thermocline, and hypolimnion. Temperature profiles will be taken at the time of water sampling. Stream and lake water samples will be collected, filtered, and

handled according to procedures adopted by the Aquatic Effects Task Group."

Status: During 1984 lake samples will be taken once during winter, twice during spring runoff, and once during midsummer and late fall. With the exception of Trout these lakes show no evidence of stratification. Even so discrete samples will continue to be taken at the depths shown in the 1983 Progress Report.

- H. "Biological measurements characterize the system and establish a baseline of indicator species. Stream measurements will include monthly sampling (April - October) of periphyton, organic C, diatom species composition on artificial substrates for a multiple year period, and a one-year monthly qualitative survey (Surber sampler) of stream invertebrates. Lake biological sampling will follow the protocol of water sampling. Zooplankton abundance and species composition will also be determined using the above sampling protocol."

Status: This will be undertaken in 1984.

- I. "There will be an annual sampling (electrofishing) of stream fish populations on a site-by-site basis. In addition, there will be an annual mid-summer lake fish survey conducted on each site using a variety of techniques. Tissue subsamples will be preserved in a 5% formaldehyde solution. Attempts will be made to elicit U.S. Fish and Wildlife assistance for these activities."

Status: This will be discussed in March 1984.

- J. "Paleolimnology for obtaining a historical record will be determined from sediment cores taken in selected lakes within the study area. One core will be pulled from the deepest part of each lake and will be dated by radiometric ( $Pb^{210}$ ) methods and analyzed for metals (Pb, Cs, Fm, Hb, Cu) and organic content movement, following the procedures of Norton et al. (1980). Other investigations will include pollen analysis and diatom identification and community structure."

Status: This will be done during the summer of 1984.

ECOSYSTEM COMPONENT: ROCK (GEOLOGY/WEATHERING)

Core Requirement

- A. "Existing records and qualitative information on surficial and structural geology (at standard U.S.G.S. scales) will be summarized."

Status: Excellent geological maps, both surficial and structural at standard U.S.G.S. scales exist for all sites (Huber, 1975; Dorr and Eschman, 1970). These data have been summarized for the two Isle Royale watersheds and the Trout Lake data will be summarized this winter.

ECOSYSTEM COMPONENT: FIRE

Core Requirements

- A. "Existing records and qualitative information on fire history and fire scar data should be recorded."

Status: Fire history for the two Isle Royale sites has been well-documented. A portion of the Wallace Lake watershed burned in 1936 in a fire that covered 20% of the island. There is no evidence of fire in the last 125 years in the remainder of the Wallace Lake or Sumner watersheds. Trout Lake is surrounded by stands of virgin white pine and there is no evidence of fire disturbance there in the last 150 years.

ECOSYSTEM COMPONENT: FAUNA

- A. No core requirements.

Status: While not site specific, very good long-term data exist showing the variation in herbivore pressure on vegetation types for much of Isle Royale (Janke, 1976; Krefting, 1974; Peterson, 1977). Also, species lists for mammals, birds, herps and fish have been compiled for the island. The moose and wolf populations on the island have been the focus of long-term predator/prey studies which began in 1959 and are still underway. A survey of mammals has also been completed for the Huron Mountain area of Michigan which includes Trout Lake.

### SCOPE OF WORK

TOPIC: Effects of Atmospheric Acid  
Deposition on Watershed/Lake Ecosystems  
of Isle Royale and Michigan's Upper  
Peninsula.

PERIOD OF STUDY: February 84 - January 85.

ESTIMATED COST: Not to exceed \$99,100.

#### 1. Objectives:

As was the case for last year, this year's emphasis will be on completing the initiation of core requirements studies in the experimental watersheds, and on completion of those baseline data components which are to be conducted on a five-year cycle. In addition, general site descriptive material will be completed this year along with the final additions of meteorological equipment. The specific objectives of this multi-year research project are as follows:

Develop input/output budgets for the watersheds and lakes to further test the hypothesis that acidification of freshwater systems can be viewed as the titration of ecosystem bicarbonate.

Assess the potential for anion mobility in the moderately acid spodosols of the region, and compare results from more organic soils (boreal) to those from northern hardwood systems.

Compare ecosystem responses to spring snowpack runoff and nutrient release, and in particular examine differences in aquatic chemistry of poorly-buffered ecosystems which receive different snowfall and snowpack accumulations.

Initiate steps to obtain data on atmospheric concentrations of ozone,  $\text{NO}_x$ , and  $\text{SO}_2$ .

Conduct a preliminary inter-site comparison (Isle Royale, Rocky Mountain, Sequoia-Kings Canyon) of data to test hypothesis that differences in bedrock geology among sites is less important in determining ecosystem sensitivity to acid inputs than is the extensiveness and quality of glacial and alluvial deposits and vegetation.

Assure adherence to current EPA-recommended protocols in the gathering and analyses of samples collected as part of the routine ecosystem monitoring.

## 2. Justification for Scope of Work:

The Master Cooperative Agreement (CA 6000-4-8002) between the National Park Service and Michigan Technological University, provides the basis for transmittal of this Scope of Work to the University as defined in the Federal Grant and Cooperative Agreement Act of 1977.

This Scope of Work addresses the research to be performed on studying the effects of atmospheric acid deposition on watershed/lake ecosystems of Isle Royale and Michigan's Upper Peninsula.

## 3. Work to be Performed:

The major difficulty in the work performed to date has been finding a lake/watershed ecosystem that is sensitive, i.e. with alkalinity less than 200 $\mu$ eq., yet sufficiently protected by law to allow truly long-term research to be conducted on it. Such a site is needed to round out the spectrum of site types being studied. One site was followed from 9/81 to 4/83 only to lose it to human site disturbance. Fortunately, only routine monitoring was conducted on it without any intensive studies done. Last summer (1983) another suitable site was found which meets the sensitivity criterion and which is protected by law and is reasonably accessible. This site, Trout Lake in the granitic Huron Mountains of Michigan's Upper Peninsula, must yet be fully instrumented and background descriptive material assembled. This will be one of the major tasks to undertake this spring and summer. Fortunately, some similar work must yet be done on the Isle Royale sites so the teams employed in such can also do the work on Trout Lake. The specific work items to be completed in 1984 are the following:

Continuation of lake limnological studies as outlined in last year's proposal revision submitted to R. Herrmann. All three lakes will be examined as to plankton communities, major ionic species, pH, alkalinity, conductivity, temperature, light attenuation, chlorophyll a, and primary productivity a minimum of four times: twice during spring runoff, once during mid-summer, and once during late fall. One winter series will be collected, but due to the extreme conditions will not include light attenuation,

primary production, or the determination of chlorophyll a.

Completion of biomass data and soils data on vegetation plots within Sumner and Trout Lake watersheds. This initial survey will, as those initiated in 1983, be quite detailed (see 1983 Progress Report). In addition, there will also be developed stand equations that are site-specific for these experimental areas. For details as to the procedures used refer to last year's proposal revision, p 21 - 23.

Completion of the soil anion mobility study on low organic sites (northern hardwoods) and in high organic sites (boreal conifers). This study was initiated in the summer of 1983 and the progress to November 1983 is discussed in the 1983 Progress Report. This study will lead to a thesis which will be completed by June 1985.

Analysis of stream, lake, and precipitation for trace metals. The protocol for such sampling and the testing of detection limits using ICPE was conducted in 1983. With the exception of Al and Zn it appears the ICPE will work for most of our samples. Therefore, data answering the core question on trace metal budgets will be gathered starting in May 1984. This involves analyzing trace metal concentrations in all lower-station streamflow, precipitation samples, selected litter samples, and the lake samples gathered during lake biological studies. All analyses except for Al and Zn, if the latter is still considered important, will be ran on ICPE. Al and Zn will be analyzed on AA.

The Remote Area Weather Station is now being tested out at the Houghton NADP site. It will be installed to begin monitoring the Wallace and Sumner watersheds in May 1983. The present meteorological instruments at this site along with a radiation monitor will be installed at the Trout Lake site by June.

All vegetation plots will have photopoints established and the first photo series taken. See revised proposal for details.

Qualitative phenological observations will be initiated this year. These will be confined to a selected set of the more significant shrub and tree species found in the watersheds. This list will be developed by spring from the vegetation plot data acquired last year (see 1983 Progress Report).

Litter layers will be sampled according to the protocol outlined in the program proposal now under revision. These samples will be analyzed using methods identical to those presented in the 1983 Progress Report. The only addition is that the initial sets will also be analyzed for trace metals.

A qualitative survey of stream benthic invertebrates will be undertaken at six locations in the three watersheds. The station locations will be at the point of stream input into the lakes and within one-hundred meters from the lake output. These animals will be identified to the genera level using the specimen key presently available for Isle Royale.

Benthic lake sediment cores will be taken at two locations in each of the lakes. These cores will be taken by an individual under sub-contract who has had considerable experience in such sampling. The cores will be analyzed for pollen distribution and heavy metals with diatom communities analyzed during the fall or early next year.

#### 4. Budget:

##### Equipment

|                                        |         |
|----------------------------------------|---------|
| Manning 4400 Automatic Sampler         | 2400.00 |
| Portable TRS Computer                  | 900.00  |
| Daisy wheel printer                    | 1400.00 |
| Manning stage height sensors (6)       | 840.00  |
| Motorola Portable 2-way radio          | 1500.00 |
| 16' Lund aluminum boat with harness    | 2000.00 |
| Dionex column kit for organic acids    | 500.00  |
| Dionex cation/anion concentrators      | 1100.00 |
| Meteorological station (wind & radiat) | 2000.00 |
| Aerochem Metrics W/D samplers (2)      | 3200.00 |

Subtotal 15,840

|                                                                                                     |          |
|-----------------------------------------------------------------------------------------------------|----------|
| Supplies                                                                                            |          |
| General lab and field supplies                                                                      | 4150.00  |
| Travel for technicians                                                                              | 2000.00  |
| Equipment maintenance                                                                               | 1200.00  |
| Subtotal                                                                                            | 7350     |
| Student and Technician Costs                                                                        |          |
| Graduate student (one year)                                                                         | 11000.00 |
| Technician (one year)                                                                               | 17200.00 |
| Post doctorate (8 months)                                                                           | 14750.00 |
| Subtotal                                                                                            | 42,950   |
| Soil, Plant Tissue, and Water Analyses                                                              |          |
| Cations, anions, organic acids for lake<br>and precipitation samples, soil, plant<br>tissue samples | 13730.00 |
| Subtotal                                                                                            | 13730    |
| Indirect Costs                                                                                      |          |
| 30% of all costs except equipment or<br>0.30 of \$64055                                             | 19216.00 |
| TOTAL                                                                                               | \$99,100 |

##### 5. Timeframe and Reports:

February 1984 to January 1985.

Progress report will be issued in February 1985.

APPENDIX C. Regression equations and references used for predicting current aboveground biomass of trees in the Wallace Lake and Noname Lake watersheds.

| SPECIES                    | FW<br>or<br>ODW   | COMPONENT | PREDICTION EQUATION                                           | N   | R <sup>2</sup><br>OR<br>r | RANGE OF<br>DBH IN CM | REFERENCE                         |
|----------------------------|-------------------|-----------|---------------------------------------------------------------|-----|---------------------------|-----------------------|-----------------------------------|
| <i>Abies balsamea</i>      | ODW-lbs           | Tree      | $\log Y = 0.086 + 2.53 \log D_1$                              | 101 | .96(r)                    | 2.5 - 25.0 cm         | Baskerville, 1965                 |
| <i>Alnus rugosa</i>        | ODW-g             | Foliage   | $\log Y = 2.1759 + 1.2463 \log D_1$                           | 30  | .67                       | 2.5 - 7.5 cm          | Ribe, 1973                        |
|                            |                   | Branches  | $\log Y = 2.4072 + 1.5184 \log D_1$                           |     | .78                       |                       |                                   |
|                            |                   | Stem      | $\log Y = 2.7051 + 2.5847 \log D_1$                           |     | .93                       |                       |                                   |
| <i>Betula papyrifera</i>   | ODW-g             | Foliage   | $\log Y = 2.1587 + 1.7020 \log D_1$                           | 30  | .89                       | 2.5 - 15.0 cm         | Ribe, 1973                        |
|                            |                   | Branches  | $\log Y = 2.4059 + 1.7304 \log D_1$                           |     | .88                       |                       |                                   |
|                            |                   | Stem      | $\log Y = 2.4481 + 3.2640 \log D_1$                           |     | .99                       |                       |                                   |
|                            | FW-lbs<br>ODW-lbs | Tree      | $\ln Y = .8025 + 2.2234 \ln D_1 + .3390 \ln H_1$<br>42% of FW | 17  | .97<br>.97                | 15.3 - 29.0 cm        | Young, 1964                       |
| <i>Picea glauca</i>        | ODW-lbs           | Tree      | $\log Y = 0.150 + 2.48 \log D_1$                              | 13  | .99                       | 2.5 - 25.0 cm         | Baskerville, 1965                 |
| <i>Picea mariana</i>       | ODW-lbs           | Tree      | $\log Y = 0.150 + 2.48 \log D_1$                              | 13  | .99                       | 2.5 - 25.0 cm         | Baskerville, 1965                 |
| <i>Pinus banksiana</i>     | ODW-kg            | Tree      | $\log Y = -1.0368 + 2.4206 \log D_2$                          | 77  | .99                       | 2.9 - 31.7 cm         | Hegyi, 1972                       |
| <i>Populus tremuloides</i> | ODW-kg            | Tree      | $\log Y = -3.2198 + 0.8993 \log D_8$                          | 49  | .99(r)                    | 4.5 - 33.0 cm         | Peterson, Chan<br>and Cragg, 1970 |
| <i>Salix</i> spp.          | ODW-g             | Foliage   | $\log Y = 2.1879 + 1.6442 \log D_1$                           | 30  | .67                       | 2.5 - 7.6 cm          | Ribe, 1973                        |
|                            |                   | Branches  | $\log Y = 2.4822 + 1.6624 \log D_1$                           |     | .77                       |                       |                                   |
|                            |                   | Stem      | $\log Y = 2.7610 + 2.3391 \log D_1$                           |     | .91                       |                       |                                   |
| <i>Thuja occidentalis</i>  | ODW-g             | Foliage   | $\log Y = 1.59 + 2.07 \log H_1$                               | 36  | .94                       | < 14.0 cm             | Dyer, 1967                        |
|                            |                   | Branches  | $\log Y = 0.59 + 2.37 \log H_1$                               |     | .89                       |                       |                                   |
|                            |                   | Stem      | $\log Y = -0.32 + 3.07 \log H_1$                              |     | .95                       |                       |                                   |
|                            | ODW-lbs           | Tree      | $\log Y = 0.037297 D_6$                                       | 113 | .90                       | 2.5 - 120 cm          | Kurucz, 1961                      |

Where:  $D_1$  = Diameter at breast height (in.)  
 $D_2$  = Diameter at breast height (cm)  
 $D_6 = (D_2^2 H)$  = Diameter at breast height squared (in.<sup>2</sup>) x height (ft.)  
 $D_8 = (D_2^2 H)$  = Diameter at breast height squared (cm<sup>2</sup>) x height (cm)  
 $H_1$  = Height above ground (ft.)

APPENDIX D. Species present in the sample plots of the Wallace and Noname Lake watersheds but contributing less than 3.0% to the aboveground current growth of the herb and shrub/tall herb strata.

#### WALLACE LAKE WATERSHED

##### HERBS

*Actaea* sp., *Anaphalis margaritacea*, *Botrychium* sp., *Chimaphila umbellata*, *Coptis groenlandica*, *Cornus canadensis*, *C. stolonifera*, *Corylus cornuta*, *Diervilla lonicera*, *Dryopteris spinulosa*, *Epilobium angustifolium*, *Fragaria virginiana*, *Galium triflorum*, *Goodyeara* sp., *Hepatica americana*, *Heracleum maximum*, *Lactuca* sp., *Lonicera dioica*, *Maianthemum canadense*, *Melampyrum lineare*, *Mitchella repens*, *Mitella nuda*, *Pteridium aquilinum*, *Pyrola secunda*, *Rosa acicularis*, *Rubus pubescens*, *R. strigosus*, *Sambucus pubens*, *Streptopus roseus*, *Taraxacum officinale*, *Trientalis borealis*, *Vaccinium* sp., *Viburnum edule*, and *Viola* spp.

##### SHRUBS/TALL HERBS

*Actaea pachypoda*, *Amelanchier* sp., *Aralia nudicaulis*, *Diervilla lonicera*, Grasses/Sedges, *Heracleum maximum*, *Lactuca* sp., *Lonicera canadensis*, and *Lonicera dioica*.

#### NONAME LAKE WATERSHED

##### HERBS

*Achillea millefolium*, *Aralia nudicaulis*, *Arctostaphylos uva-ursi*, *Chimaphila umbellata*, *Clintonia borealis*, *Coptis groenlandica*, *Dryopteris disjuncta*, *Epilobium angustifolium*, *Fragaria virginiana*, *Galium triflorum*, *Linnaea borealis*, *Lycopodium obscurum*, *Maianthemum canadense*, *Melampyrum lineare*, *Mitchella repens*, *Mitella nuda*, *Pyrola secunda*, *Rubus parviflorus*, *R. pubescens*, *R. strigosus*, *Solidaga* sp., *Streptopus roseus*, *Trientalis borealis*, *Vaccinium* sp., and *Viola* spp.

##### SHRUBS/TALL HERBS

*Diervilla lonicera* and *Rosa acicularis*.