29 September, 1999

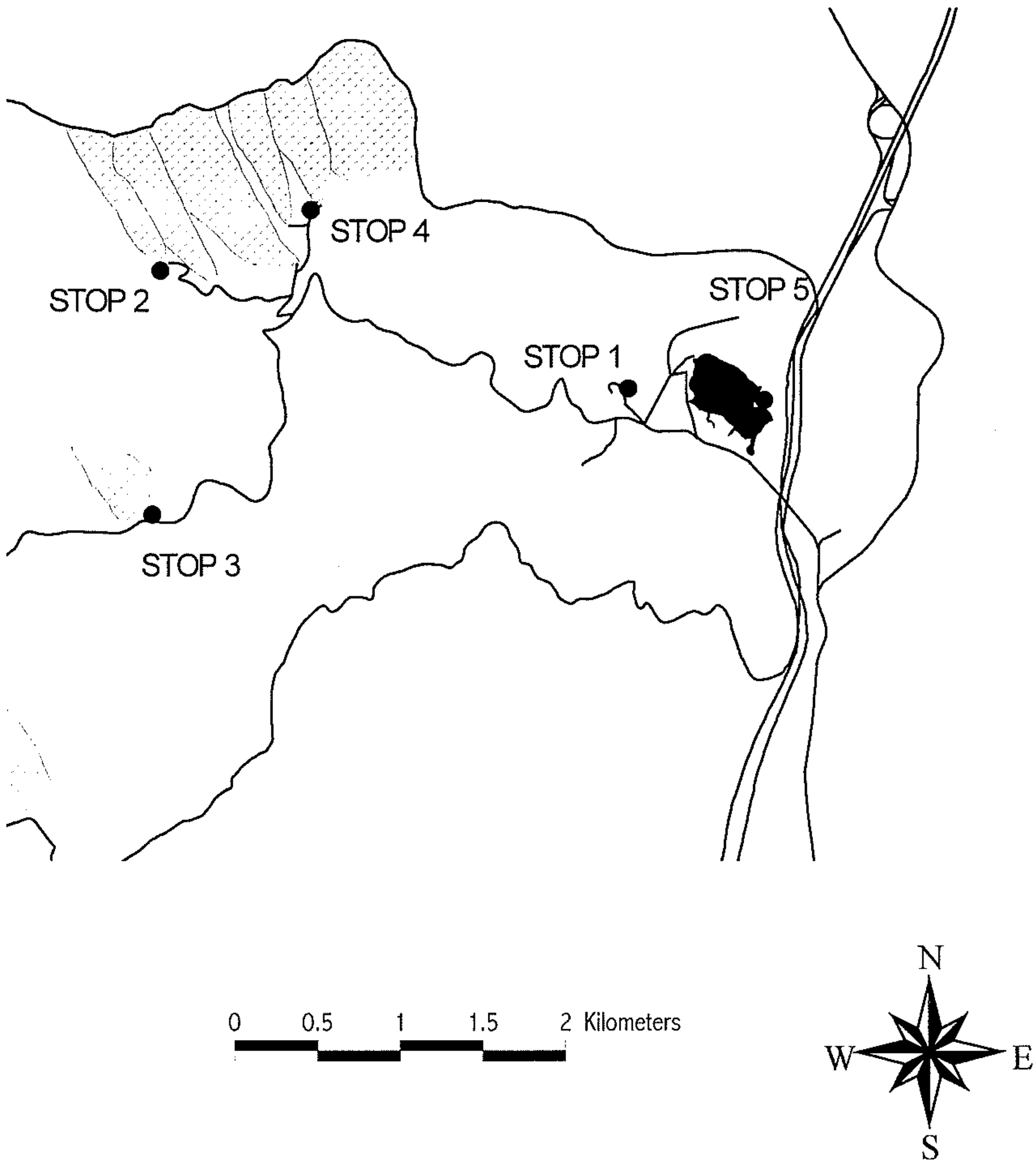
Fall 1999 LTER Coordinating Committee Meeting
Hubbard Brook Experimental Forest

RESEARCH SITES OF THE HUBBARD BROOK EXPERIMENTAL FOREST

This hand-out material is a summary of some of the field sites at the Hubbard Brook Experimental Forest, NH. The field trip will include five stops and discussion of activities, adjacent to each stop.

STOP 1	**R.S. Pierce Laboratory**	
	Overview of the HBES	- C. Eagar, USFS
	Activities near the Pierce Laboratory	- A. Bailey, USFS
STOP 2	**Gauging Station at Watershed 6**	
	Bird Studies	- P. Doran, Dartmouth College
	Vegetation Studies	- T. Siccama, Yale Univ.
	Biogeochemical Studies	- C. Driscoll, Syracuse Univ.
STOP 3	**Freeze Plot**	
	Snowpack Manipulation Study	- P. Groffman, IES
	Ice Storm Investigation	- T. Fahey, Cornell Univ.
STOP 4	**Watershed 2**	
	Deforestation Experiment of Watershed 2	- G. Likens, IES
	Calcium Manipulation Experiment (W1)	- C. Johnson, Syracuse Univ.
	Soils at Hubbard Brook	- C. Johnson, Syracuse Univ.
STOP 5	**Mirror Lake**	
	Mirror Lake Studies	- D. Buso, IES
	Pemigewasset-Merrimack River	- K. Driscoll, Cornell Univ.

Hubbard Brook Experimental Forest



STOP 2 GAUGING STATION AT WATERSHED 6

Animal Population and Community Studies in the Northern Hardwoods Ecosystems at HBEF (N. Rodenhouse)

1. Long-term studies of bird and defoliating insect populations in northern hardwoods forests (R.T. Holmes and colleagues). Bird populations have been studied on one forest plot within HBEF since 1969 and on three additional replicate plots within nearby sections of the White Mountain National Forest since 1986. Study topics have included role of birds in ecosystem nutrient cycling and energy flow, bird-insect interactions, bird foraging behavior in relation to insect availability, and bird population ecology (reproductive success, survival, nest predation, etc.). Bird bundance patterns of 20+ species provide information on long-term population trends of birds occupying these largely undisturbed, unfragmented northern hardwoods forests (see figure). Similarly, the numbers of defoliating caterpillars have also been monitored at Hubbard Brook since the early 1970s.

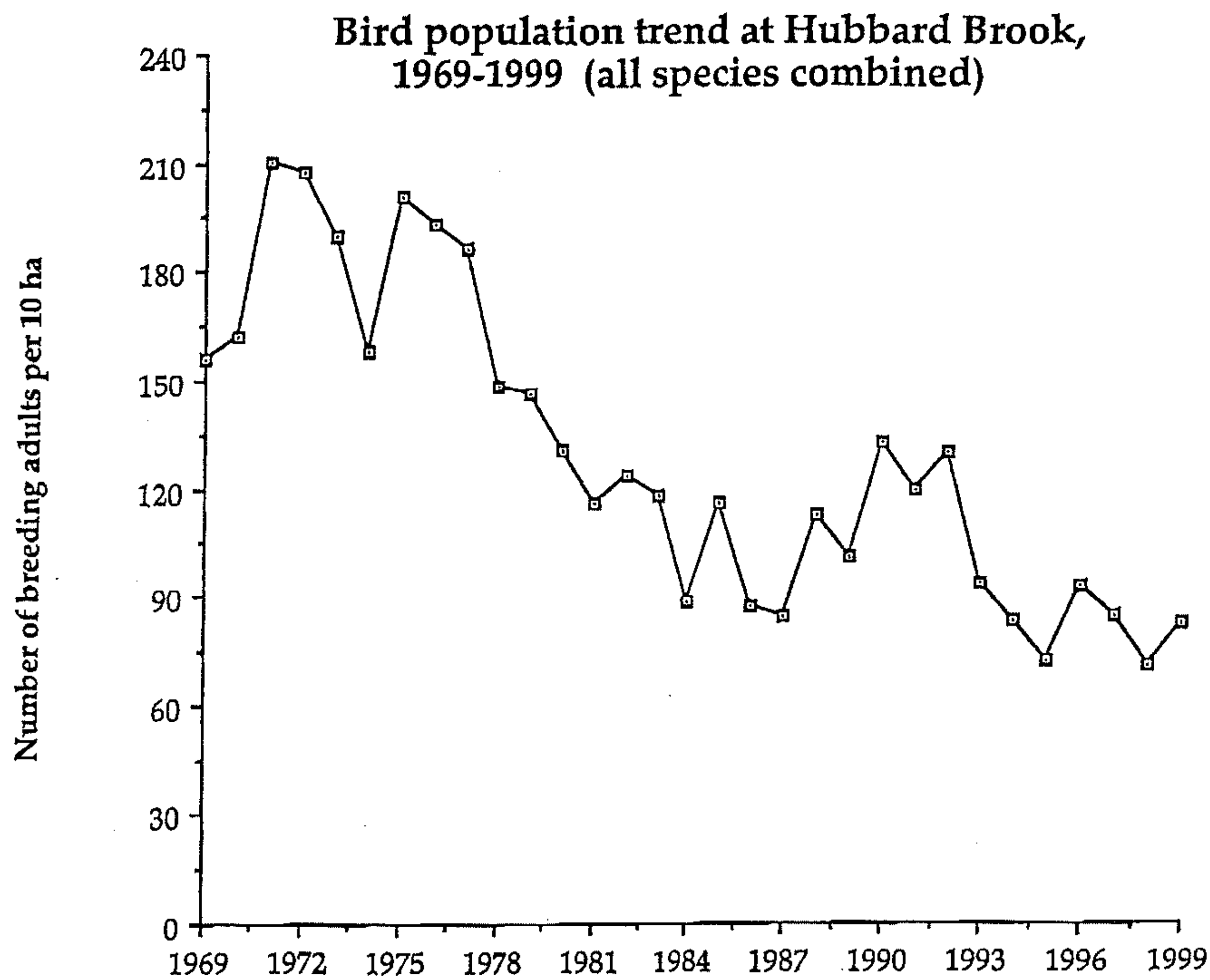
2. Impact of birds on tree growth via predation on defoliating insects (T.W. Sherry, R.T. Holmes, PI's; A.Strong, graduate student). The importance of birds as consumers of insects in forest systems has often been questioned. However, recent studies have indicated that top-down predation by birds can influence phytophagous insect population dynamics which in turn impact plant processes (e.g., plant growth -- Marquis and Whelan 1994). At HBEF, caterpillars have defoliated up to 40% of leaf biomass during irruptions (Gosz et al. 1978, Holmes et al. 1986), and avian populations respond numerically and functionally to these irruptions. Even during non-irruptive years, birds have been shown to have a significant numerical impact on defoliator populations at HBEF (Holmes et al. 1978). To test whether forest birds consume sufficient biomass of herbivorous insects to have an effect on tree growth, we are conducting an experiment, with 30 replicates per treatment, on sugar maple saplings. The treatments include (1) bird (but not insect) removal via exclosures, (2) insect removal via application of an insecticide, (3) insect supplementation, and (4) control. We are assessing shoot extension, increment in stem diameter, leaf size and number and estimated biomass increment. Insect abundances are also examined throughout the experimental period (May-August) and birds are censused in the vicinity of the treatments. Results to date indicate that birds in this forest significantly reduce the numbers of defoliating caterpillars, but not to the level where an impact of this reduced herbivory can be detected on plant growth.

3. Bird distribution and abundance at landscape scales (R.T. Holmes, PI; Patrick Doran, graduate student). Most studies of animal communities have been conducted at very small temporal and spatial scales, making assessments of the effects of natural or human-induced perturbations difficult. Furthermore, it is not clear the degree to which conclusions from studies at such small scales can be extrapolated to larger scales. For this study, we are examining the distribution and abundance

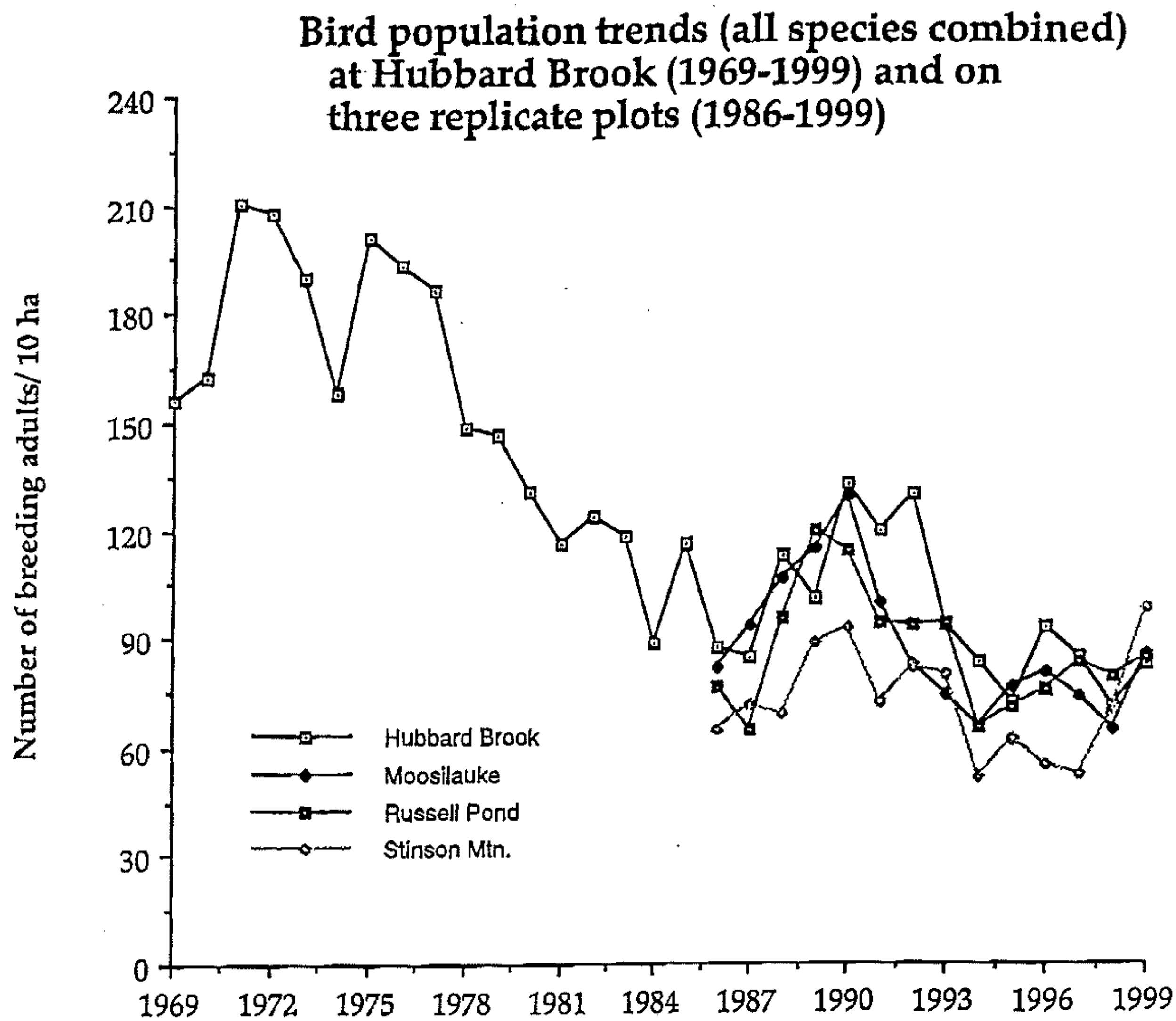
of all bird species over the entire Hubbard Brook valley, using the large-scale grid system established at HBEF by P. Schwarz and T. Fahey. This 30 km^2 valley includes strong elevational (300-800 m) and vegetational (hardwood/softwood) gradients and other environmental factors that determine patterns at the landscape level. These data will also provide a baseline for assessing changes in bird populations that may occur due to insect outbreaks or other forms of disturbance, as well as longer term changes that may occur (e.g., due to climate change).

4. <u>Determinants of population size of forest bird populations</u> (N.L. Rodenhouse, R.T. Holmes, PIs; T.S. Sillett, graduate student). This project is examining the processes and mechanisms that determine the abundances of birds that occupy the Hubbard Brook Experimental Forest and other temperate zone forests. Studies focus on the spatial variability in habitat quality and how this affects survival and reproduction, on preemptive territorial behavior, and on the effects of population density on population growth and regulation. T.S. Sillett, a graduate student at Dartmouth, is conducting a density reduction experiment as part of this project.

5. <u>Mating systems and paternity of forest birds</u> (M.S. Webster and R.T. Holmes, PI's, H.C. Chuang and L. Nagy, graduate students). This research examines the ecological basis of extra-pair matings in the socially monogamous Black-throated Blue Warbler (*Dendroica caerulescens*). Using molecular genetic techniques, we are testing for associations among territory quality, male genetic quality, female settlement, male behaviors, and the mating system. The study will yield a better understanding of the ecological causes and consequences of different mating associations and of the relative importance of habitat quality versus individual bird quality in affecting reproductive success, productivity, and fitness in forest bird species.



Bird population trend at Hubbard Brook,
1969-1999 (all species combined)
Number of breeding adults per 10 ha
240
210
180
150
120
90
60
30
0
1969
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999



Bird population trends (all species combined)
at Hubbard Brook (1969-1999) and on
three replicate plots (1986-1999)
Number of breeding adults/ 10 ha
240
210
180
150
120
90
60
30
0
1969
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999
Hubbard Brook
Moosilauke
Russell Pond
Stinson Mtn.

Vegetation Studies (T.G. Siccama)

1. Vegetation on the reference watershed (W6). A grid consisting of 208, 25-m x 25-m plots was established in 1965 which encompassed the whole of watershed 6. Utilizing this permanent grid, a subsampling of the forest was conducted in 1965 (at the pre computer/computer boundary- it was planned at that time that the calculations would have to be done on a mechanical calculator). In 1977 and every 5 years after that a total inventory of all the live and dead trees ≥ 10 cm dbh on the whole of the watershed has been done (~8000 stems). Using the allometric equation prepared on-site in 1965 by Whittaker and his associates, we have been estimating the biomass at each sampling period. Currently biomass is not accreting (mortality has equaled growth). No single factor can be linked to this leveling off in biomass accumulation but it appears to be a combination of severe mortality of sugar maple at the higher elevations (not visible from the weir), beech mortality due to the beech bark disease (although beech is still the most rapidly growing of the species in the forest) and a general decrease in growth (radial growth of comparable sized trees) of all the species relative to the growth rates on the forest in 1965. One of the most noteworthy aspects or dynamic of the forest on watershed 6 is the large increase in beech saplings (root sprouts?), presumably due to the loss of crown vigor by the older beech.

2. Forest population dynamics: The "Bird area" study. In 1991 in response to suggestions and ideas gleaned from attending an LTER workshop, we established a tagged tree inventory of all the trees on 10 ha in the central portion of the valley in the area used in the study of the bird populations. The area of this study is just down slope from the W6 weir and extends westward about 2.5 Km in 4 ten m wide transects each about 200 m apart. Plots are continuous contiguous segments of the transect, each 25 m long.

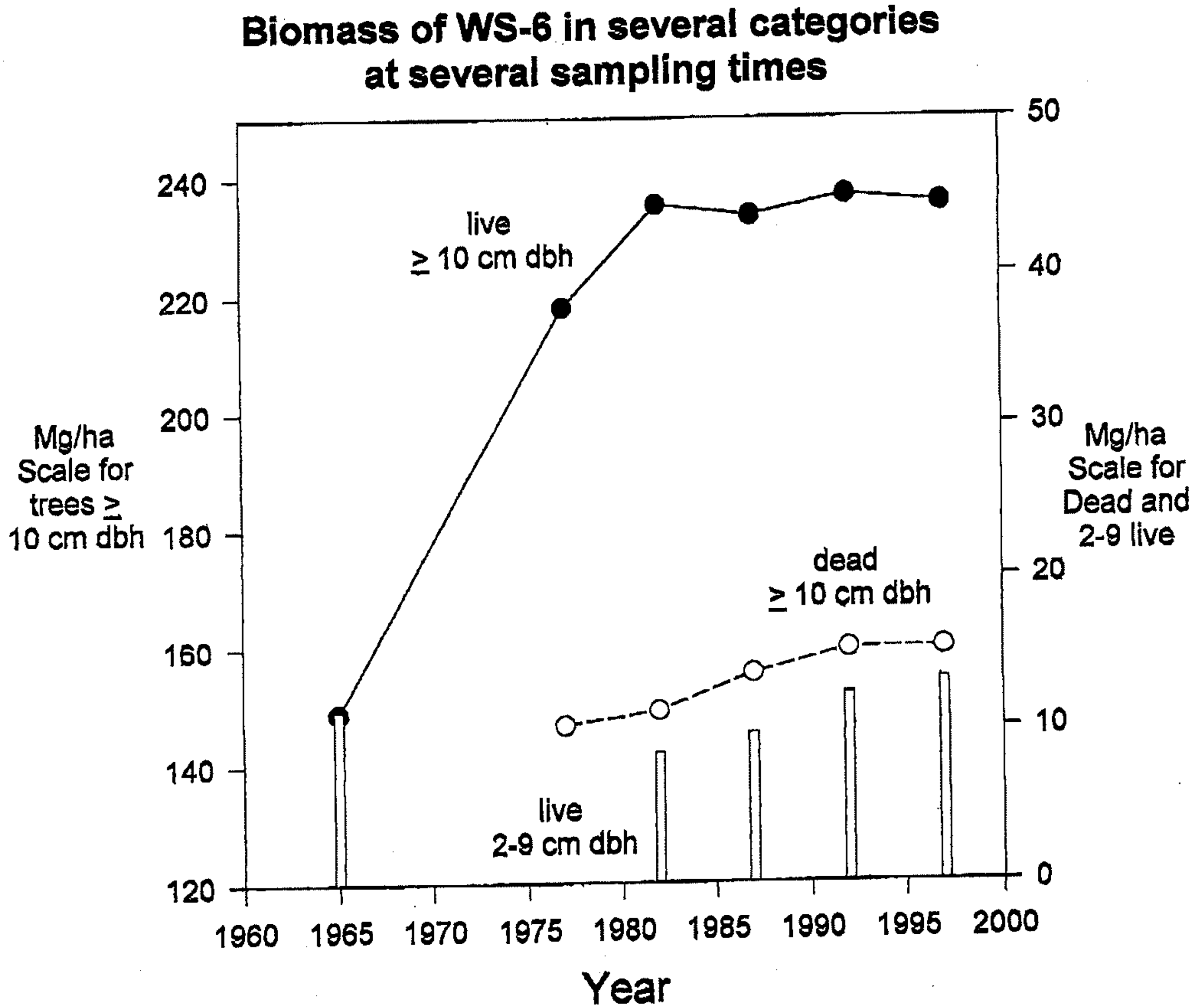
   About 5000 trees (≥ 10 cm dbh) were tagged and species and diameters were recorded in 1991. These trees have been revisited every 2 years since 1991 and the condition of each tree noted. Diameters were not recorded at these two year intervals (diameters will be recorded at the 10 year interval - 2001). We have found that mortality has been about 1%. In-growth has been predominately beech. Assuming that general forest biomass accretion has leveled off in the "Bird area" as it has on the adjacent watershed 6, we estimate that annual productivity to equal mortality has to be about 3 Mg/ha per year. This assumption of no net growth has been substanciated in part in the Bird area in that in 1995 we did measure the dbh of all the trees on one of the lines (2.5 ha of sample) and there had been no net change in biomass from 1991 to 1995.

3. Forest history recorded in tree growth responses. Two figures are attached which illustrate some of the forest history. One figure shows the lifetime growth pattern of the red spruce tree just a few meters up slope of the W6 weir on the east side of the stream. This tree shows the release in the 1870 period in which spruce was first logged from the valley. It also shows a release after 1940, presumable due to the 1938 hurricane. For this tree there was no response in the 1915 period when we

presume most of the forest was logged for hardwoods.

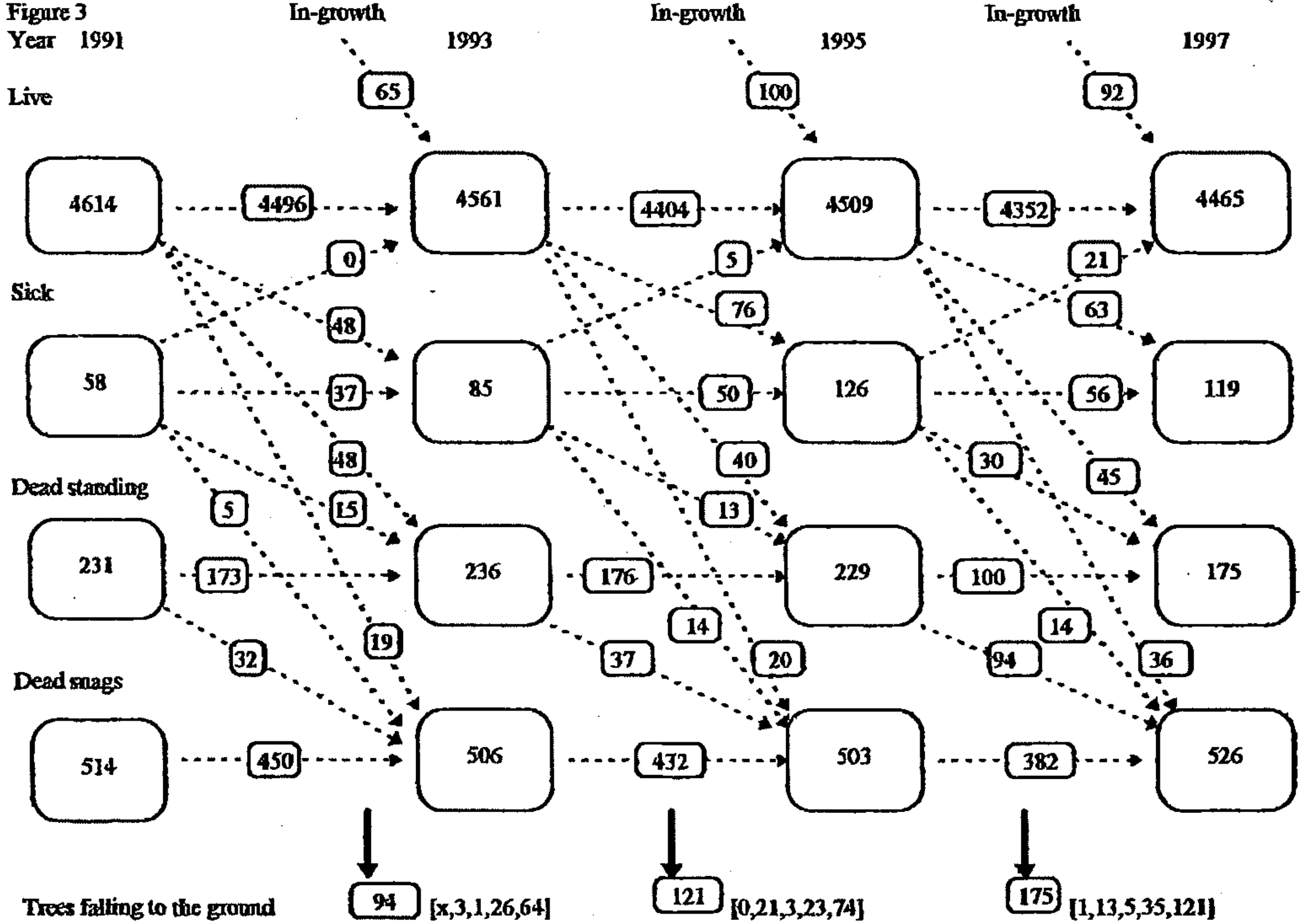
The second graph illustrates the pattern of growth for 70 mature trees of all species (mean radial growth data) obtained in 1974 from throughout watershed 6. In this set of data the 1870 and the 1938 response is also shown but the 1915 response of the general hardwood logging is also shown.

4. <u>Lead in the forest floor</u>. One of the environmental contaminates we have been monitoring since the mid 1970's is lead in the forest floor. Each time we do the forest inventory we obtain quantitative forest floor samples from 80 to 100 of the 208 grid cells. The figure illustrates the patterns of lead decline since the mid 1970's. It appears that there was an initial decline in the amount of lead in the forest floor up though the 1980's, but that decline has stabilized and the amount of lead in the forest floor has remained fairly constant since that time.

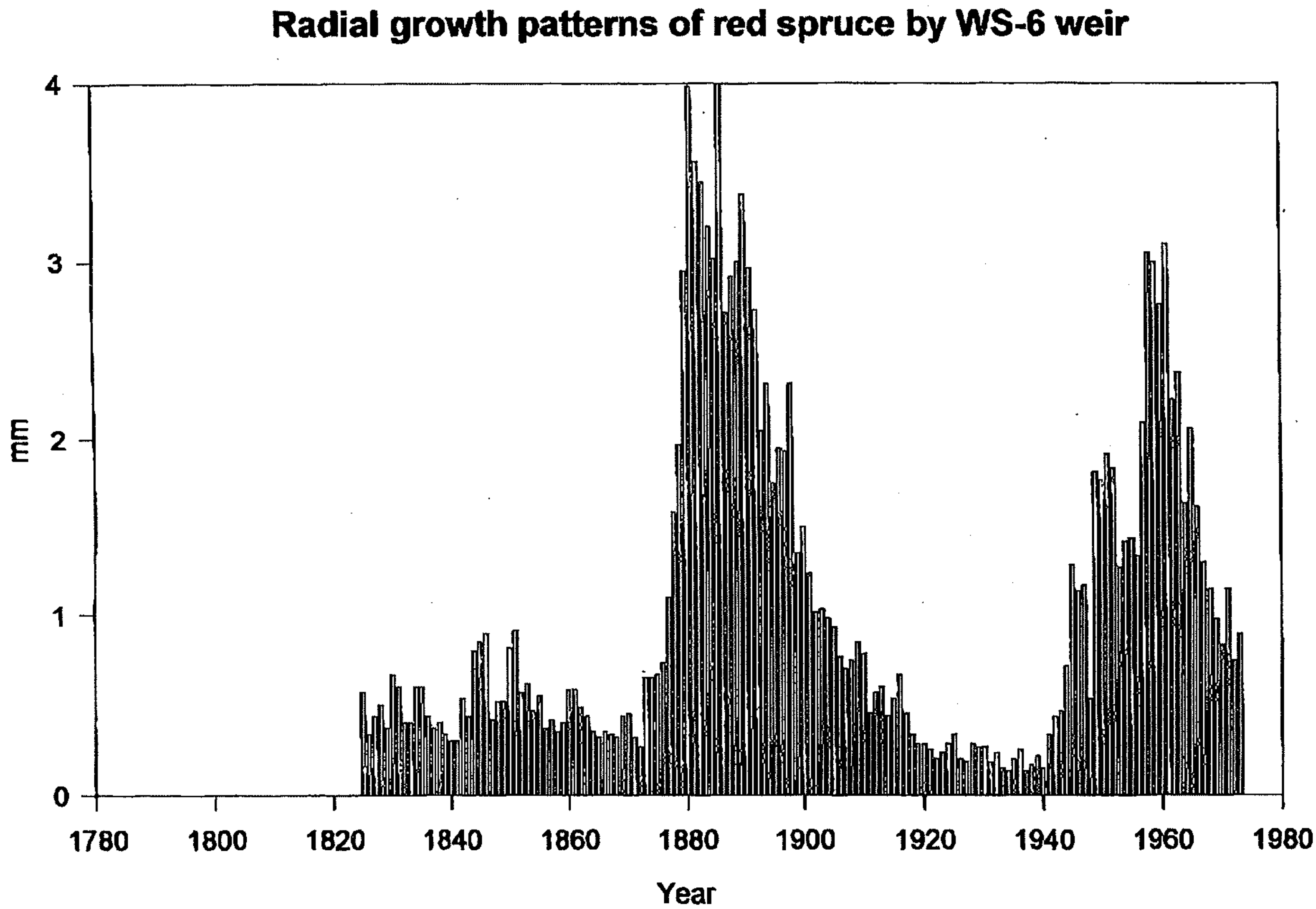


Biomass of WS-6 in several categories
at several sampling times
Mg/ha
Scale for
trees ≥
10 cm dbh
Mg/ha
Scale for
Dead and
2-9 live
live
≥ 10 cm dbh
dead
≥ 10 cm dbh
live
2-9 cm dbh
240
220
200
180
160
140
120
50
40
30
20
10
0
1960
1965
1970
1975
1980
1985
1990
1995
2000
Year

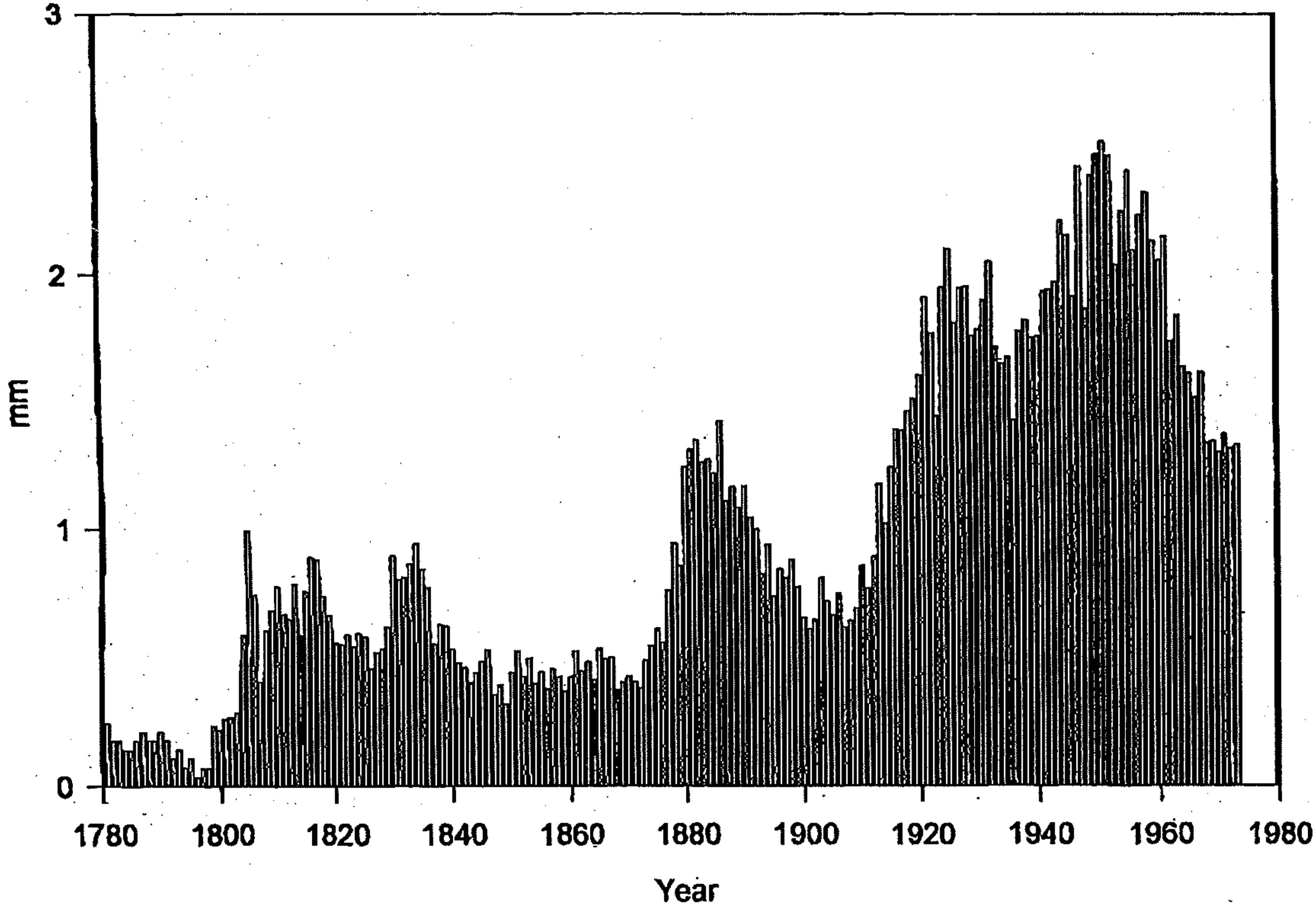
Figure 3



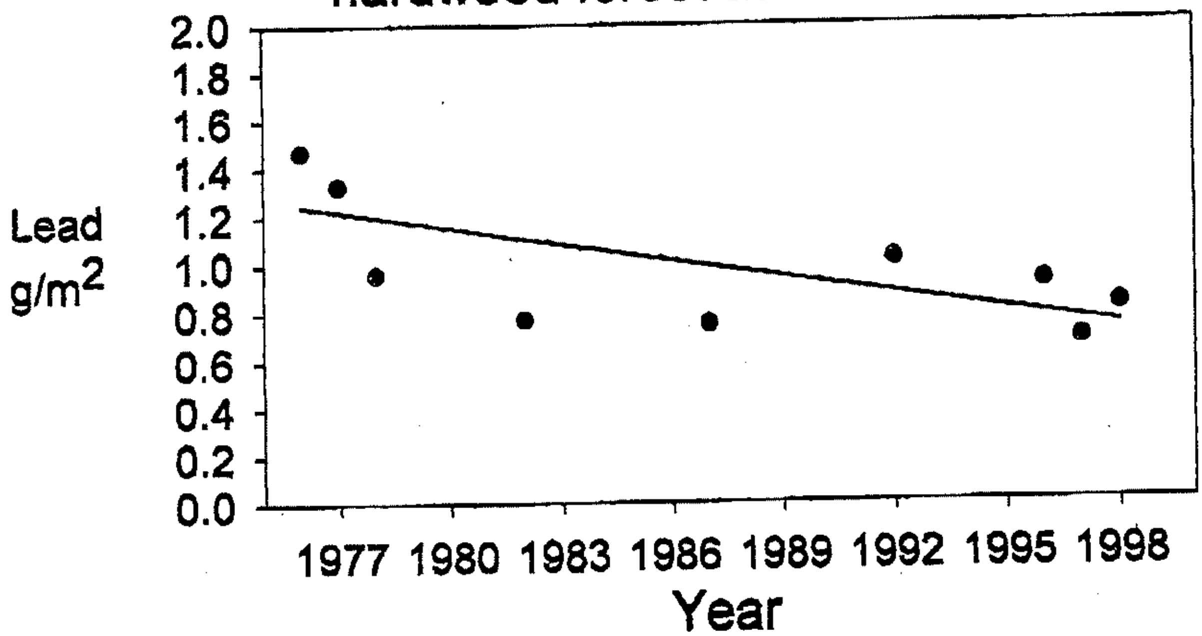
pools.doc


Radial growth patterns of red spruce by WS-6 weir
mm
4
3
2
1
0
1780
1800
1820
1840
1860
1880
1900
1920
1940
1960
1980
Year

Growth patterns of 70 trees from WS 6 collected in 1974



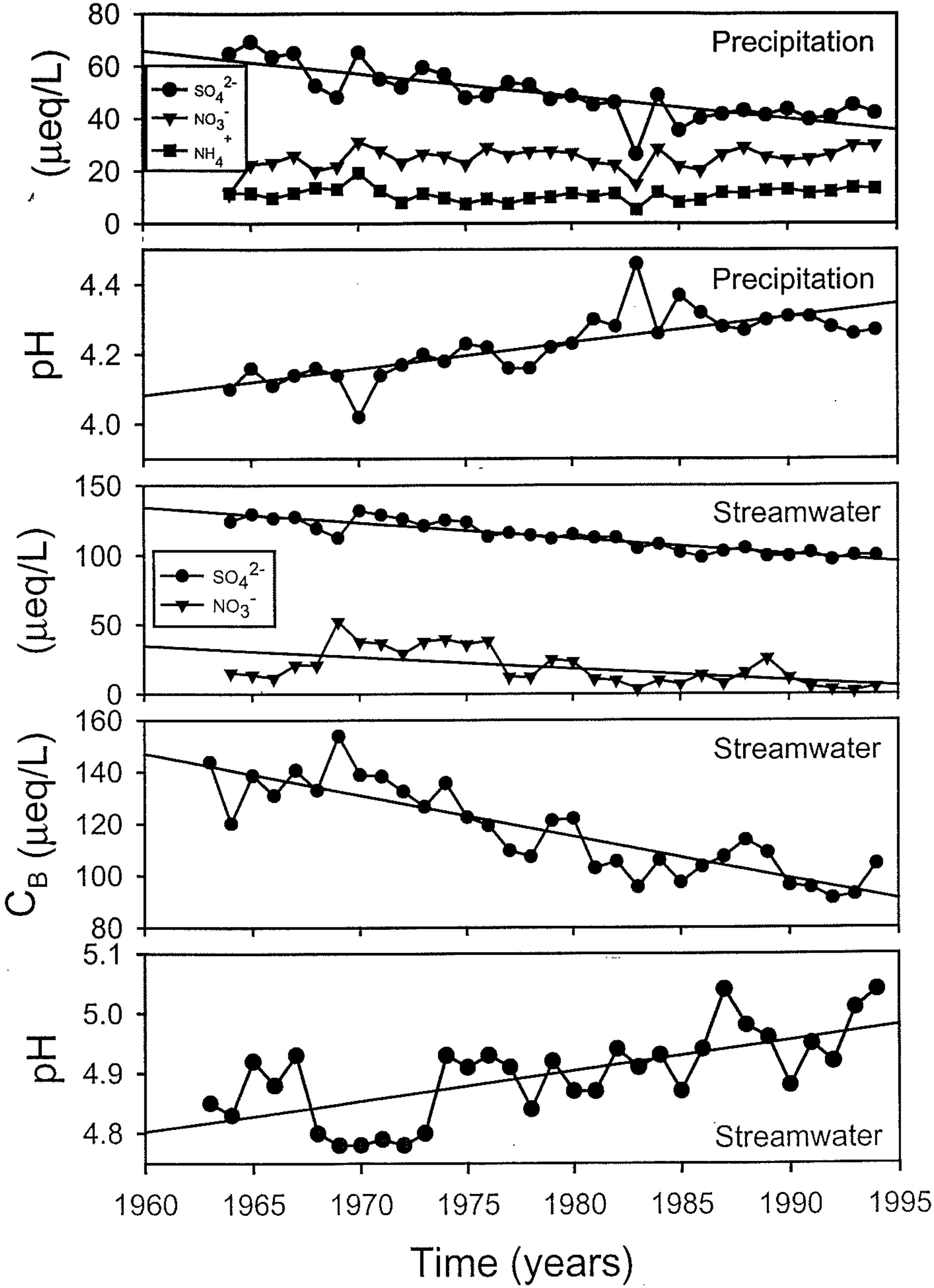
Amount of lead (Pb) in the forest floor in the northern hardwood forest at Hubbard Brook



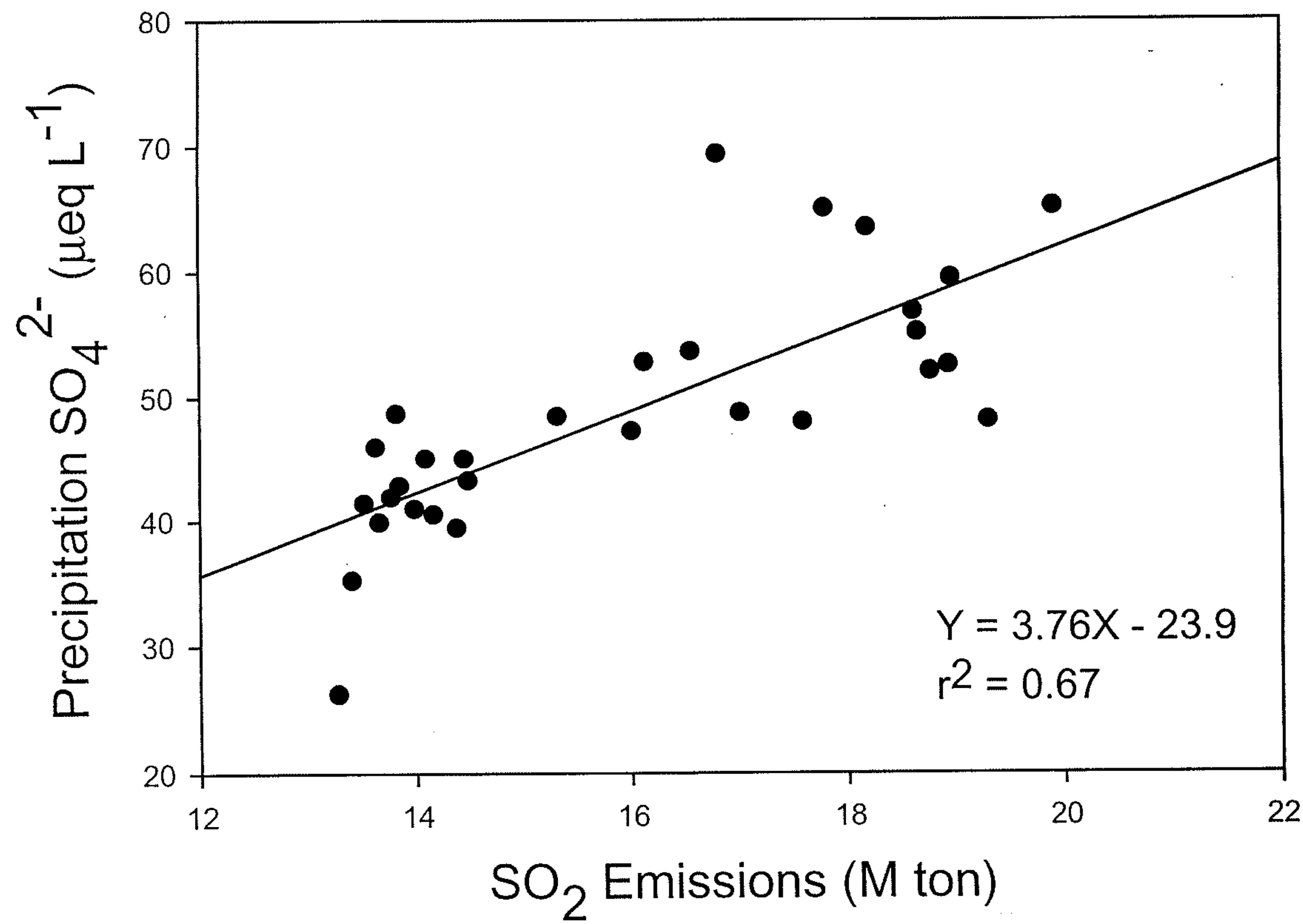
Biogeochemical Studies (C.T. Driscoll)

Watershed 6 (W6) is the long-term, biogeochemical reference watershed for Hubbard Brook. Continuous records of the amounts and chemical composition of precipitation and stream water have been maintained since 1963 (see figure). Precipitation is acidic at Hubbard Brook largely due to elevated inputs of sulfuric and nitric acids. Long-term measurements of precipitation chemistry show decreases in concentrations of sulfate in response to decreases in atmospheric emissions of sulfur dioxide in the eastern U.S. (see figure). There have been no long-term patterns in the concentrations of nitrate or ammonium in precipitation at Hubbard Brook. Over the study period there has been a significant increase in the pH of precipitation, largely coinciding with decreases in concentrations of sulfate.

Like precipitation, stream water at Hubbard Brook is acidic due to elevated concentrations of basic cations (calcium, magnesium, sodium, potassium) relative to concentrations of strong acid anions (sulfate, nitrate, chloride). Acidic stream water is characterized by elevated concentrations of aluminum, which is toxic to aquatic biota. The relatively low concentrations of basic cations are due to low rates of cation supply from mineral weathering. Sulfate, the dominant anion in stream water at Hubbard Brook, is largely derived from atmospheric deposition. As a result, stream concentrations of sulfate have also decreased in response to declines in atmospheric emissions of sulfur dioxide. Decreases in stream sulfate have coincided with stoichiometric decreases in concentrations of basic cations resulting in little change in pH. Depletion of calcium from labile pools in soil has been accelerated by inputs of acid rain. This depletion of calcium from soil may affect soil biota and forest vegetation, and has delayed the recovery of streams in response to decreases in acidic deposition.



Precipitation
(μeq/L)
SO4 2-
NO3 -
NH4 +
Precipitation
pH
Streamwater
(μeq/L)
SO4 2-
NO3 -
Streamwater
C_B (μeq/L)
pH
Streamwater
Time (years)

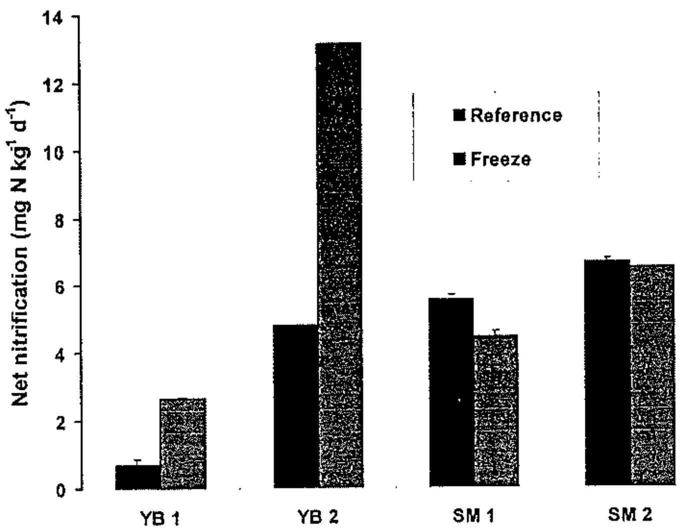


Precipitation SO4 2- (μeq L-1)
SO2 Emissions (M ton)
Y = 3.76X - 23.9
r2 = 0.67
80
70
60
50
40
30
20
12
14
16
18
20
22

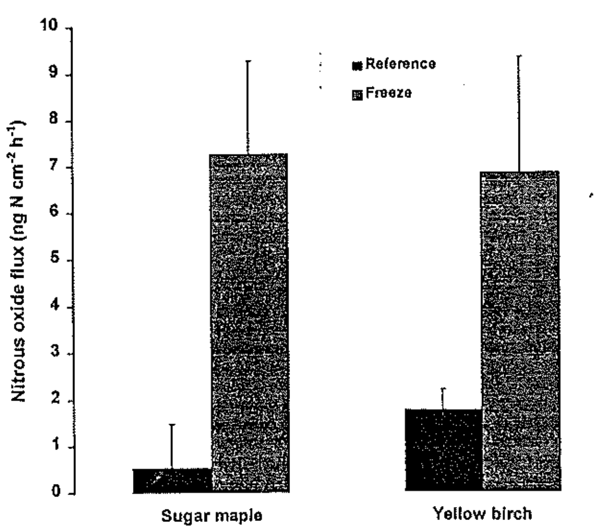
STOP 3 FREEZE PLOT

Snow Depth, Soil Frost and Nutrient Loss in a Northern Hardwood Forest (P. Groffman)

We have initiated an experiment to investigate the effects of decreases in snow cover on ecosystem processes. We manipulate snow depth by shoveling to induce soil freezing, and quantify effects on roots, microbial biomass and activity, solute leaching and trace gas fluxes in stands of sugar maple and beech. Soil freezing has produced significant increases in N mineralization and nitrification rates, solute leaching and soil nitrous oxide production, and significant decreases in soil methane uptake. Freeze effects have differed by tree species. These results suggest that freezing events influence nitrogen cycling and stream chemistry in northern hardwood forests and that tree species composition is an important regulator of this influence.



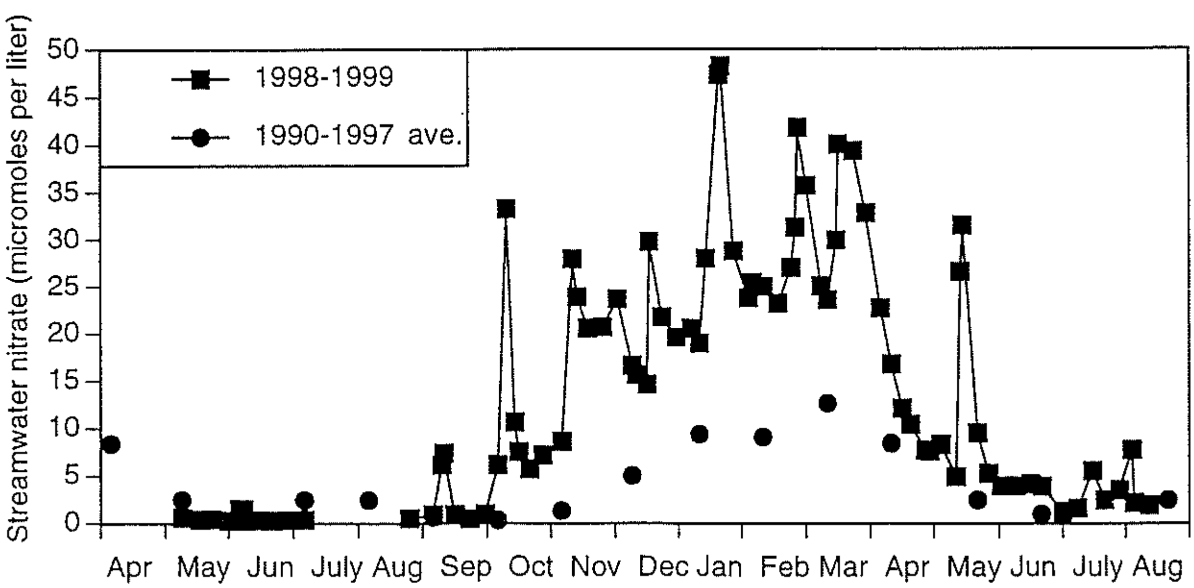
In situ net nitrification rates in the forest floor of two yellow birch (YB) and two sugar maple (SM) sites with freeze and control plots, April 1998. Values are mean with standard error.



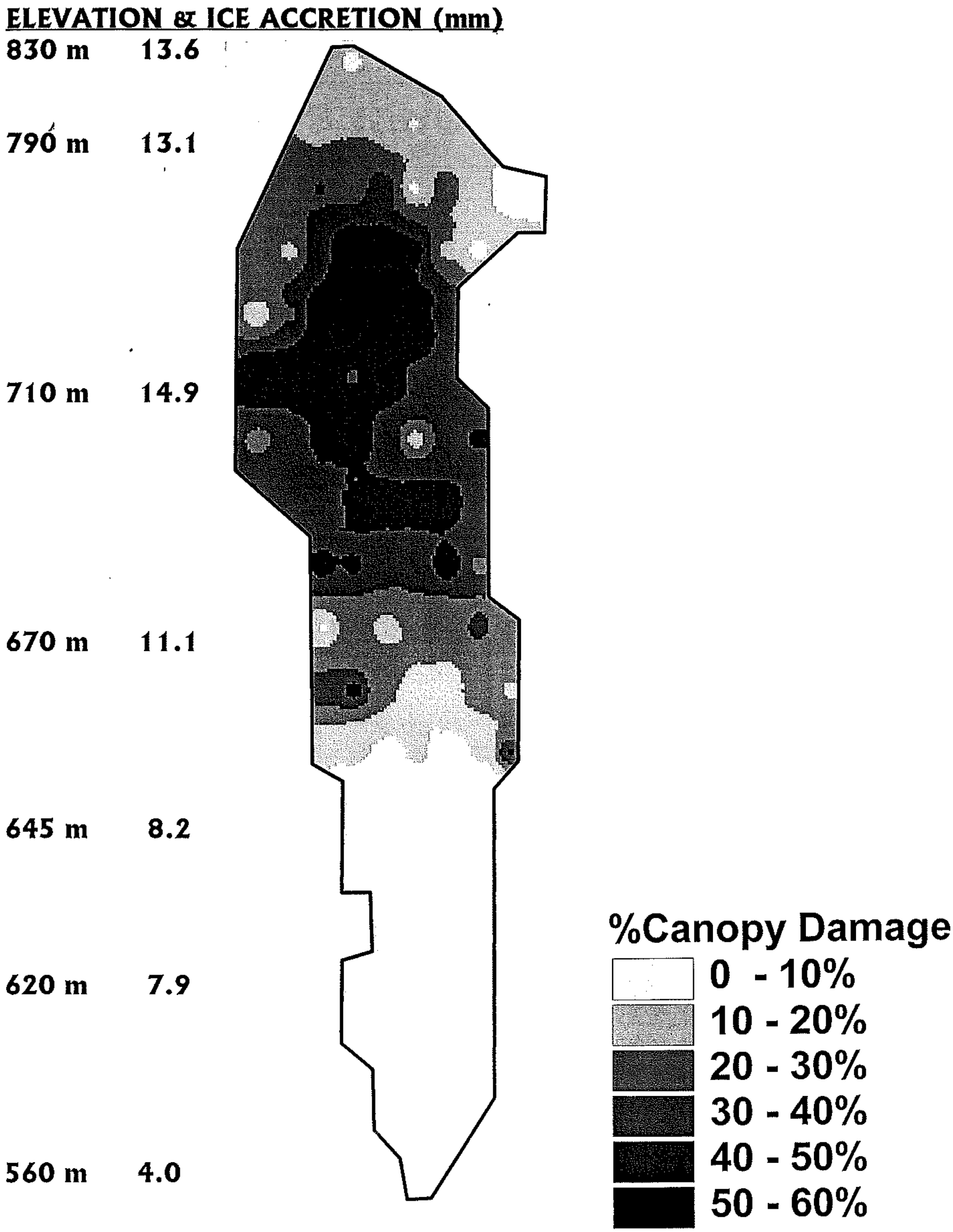
Nitrous oxide fluxes measured in *in situ* field chambers. There were three chambers placed in freeze and control plots in two yellow birch (YB) and two sugar maple (SM) sites. Values are mean with standard error of nine sampling dates between October 1997 and April 1998.

Ice Storm Investigation (T. Fahey)

In January 1998 a severe ice storm caused widespread damage to forests throughout northern New England and southern Canada, including portions of the Hubbard Brook valley. The experimental watersheds were particularly hard hit, providing an opportunity to quantify the effects of this natural disturbance on ecosystem structure and function. Based upon visual estimates of canopy damage and changes in leaf litterfall for permanent litter collection plots, canopy loss ranged from near zero at the base of watershed 6 to as high as 60% in some areas on the upper slopes. The degree of damage depended upon ice accretion (which increased with elevation; see map on reverse side), slope angle and the proportion of beech in the canopy. The watershed-wide leaf area reduction was about 30%. Significant increases in streamwater nitrate were first observed in early autumn, and during the following winter nitrate concentrations remained several times higher than the long-term average (see figure). Surprisingly, however, little change in soil microbial processing of nitrogen was observed, even in areas of very heavy ice damage.



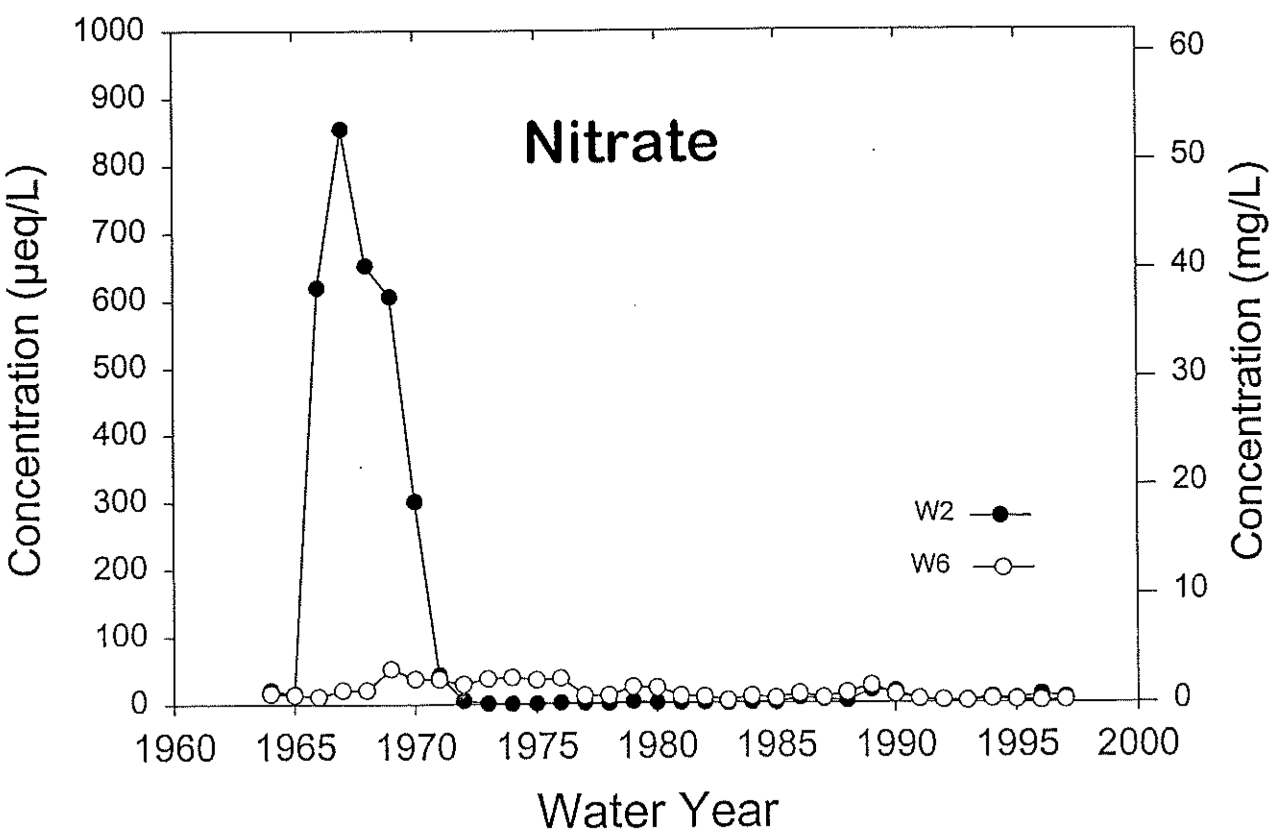
WS6 1998 Ice Storm Damage

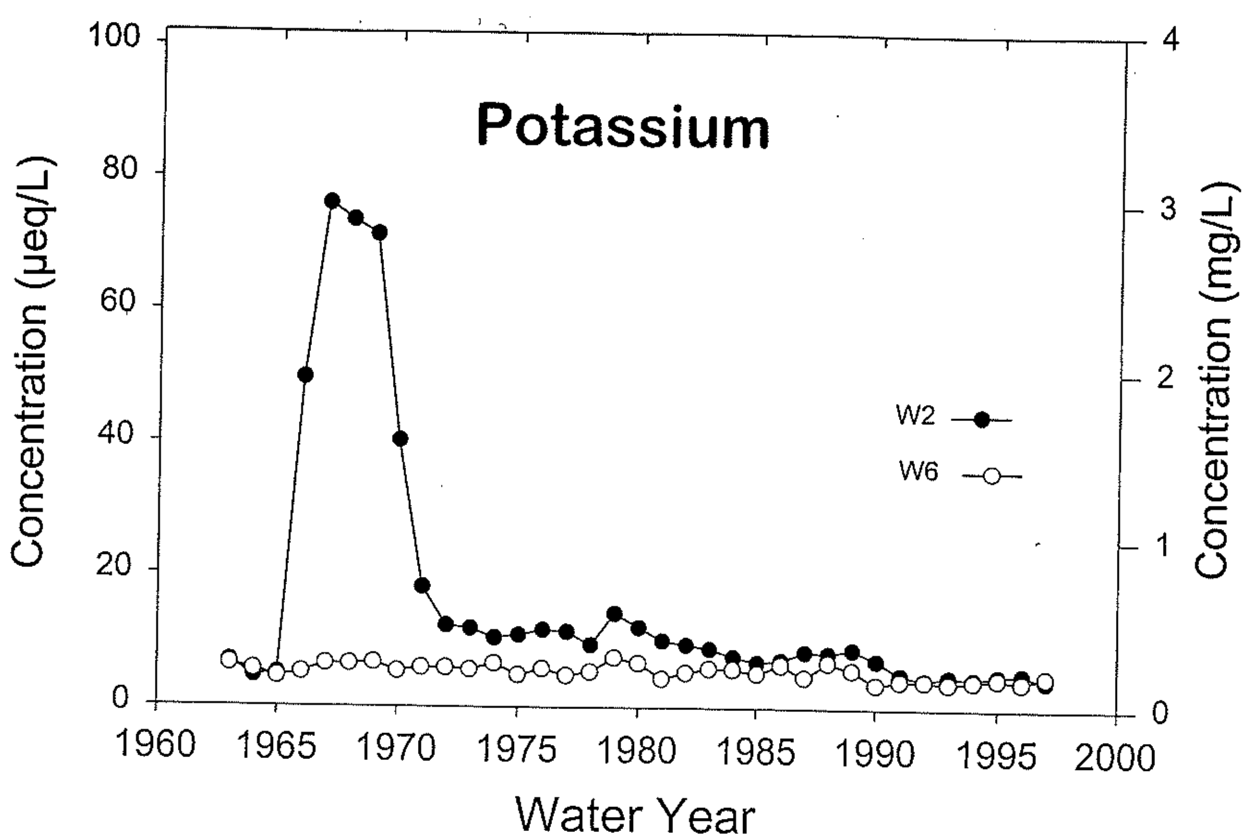


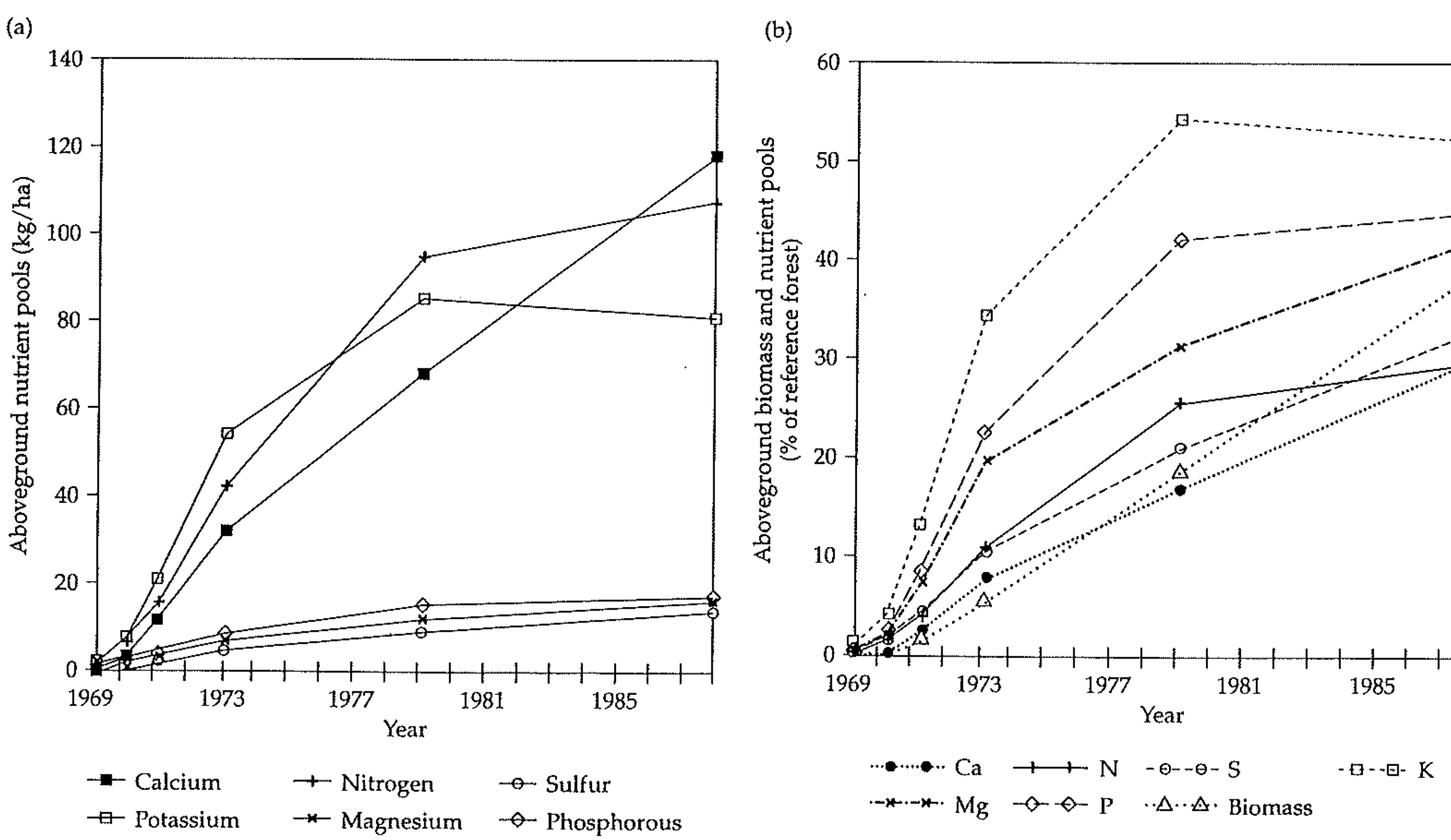
STOP 4 WATERSHED 2

Deforestation Experiment of Watershed 2 (W2) (G. Likens)

Watershed 2 was deforested during the winter of 1965-66. All vegetation was felled and left in place, with special care not to add organic material to the stream channel. Herbicides were applied during the summers of 1966, 1967, and 1968 to prevent regrowth. The objective of this study was to examine the role of vegetation in nutrient cycles. Long-term measurements of vegetation recovery (Reiners), log decomposition (Tritton and Siccama) and organic debris dams (Hedin and Likens) have been done. Continuous measurements of amounts and chemical composition of streamflow have been done since 1963 (see figures). During and immediately following disturbance, mineralization of soil nitrogen and nitrification resulted in large releases of nitric acid and acidification of soil and streamwater. Elevated leaching losses of nitrate, nutrient cations (see figure) and aluminum occurred. We have followed the recovery of vegetation and nutrient cycling in W2. After 20 years, the vegetation pools of major nutrients remained less than 50% of the mature forest (see figure), and the trajectories for nutrient accumulation indicated contrasting behavior among nutrients. Moreover, systematic variation in recovery was observed within watershed 2. In summer 1999, we completed the 30-year re-inventory of watershed 2, hoping to identify the long-term patterns and trajectories for ecosystem recovery in the landscape. These patterns are now overlain by effects of the 1998 ice storm on the watershed 2 forest, an event that will both complicate and make more interesting the analysis of the recovery of this watershed-ecosystem.

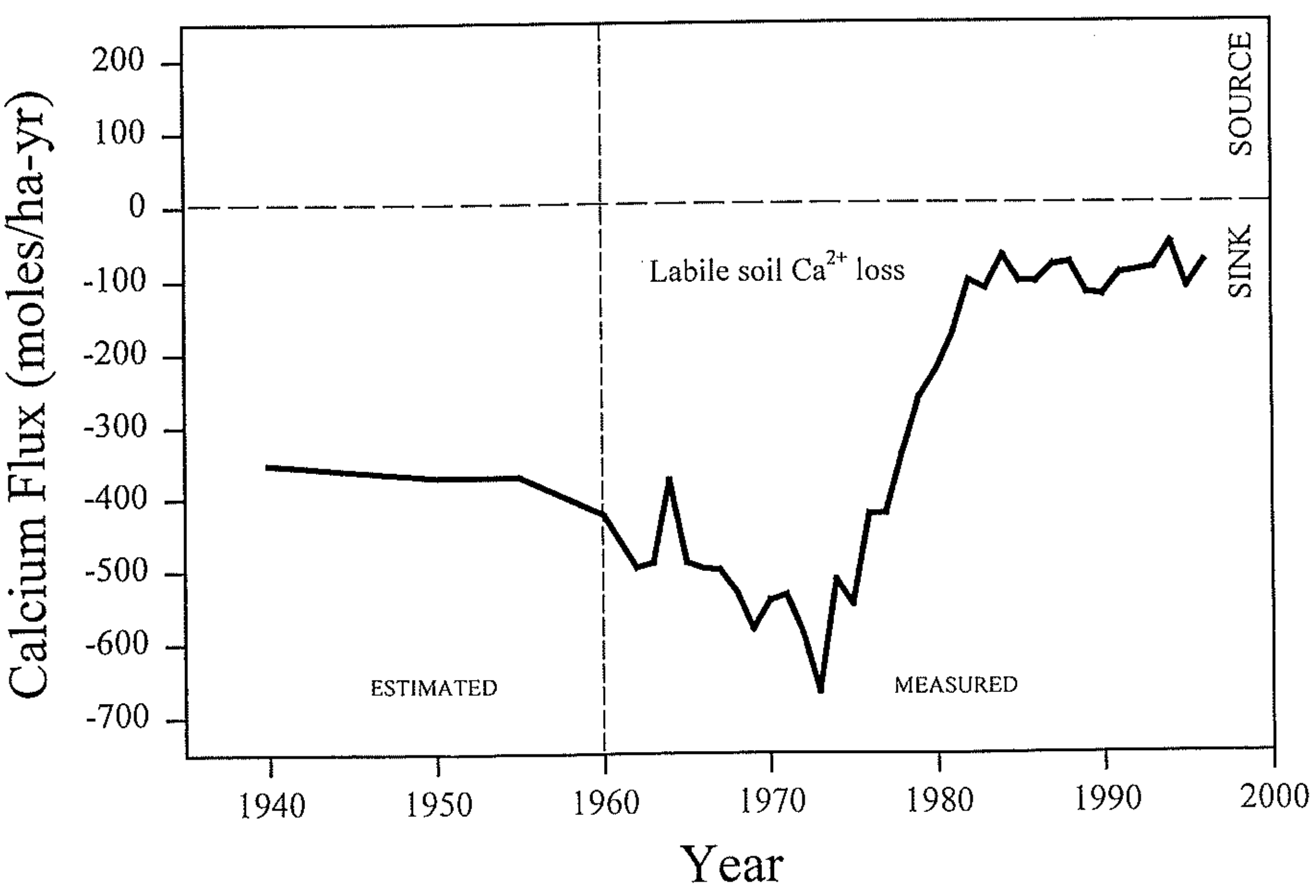


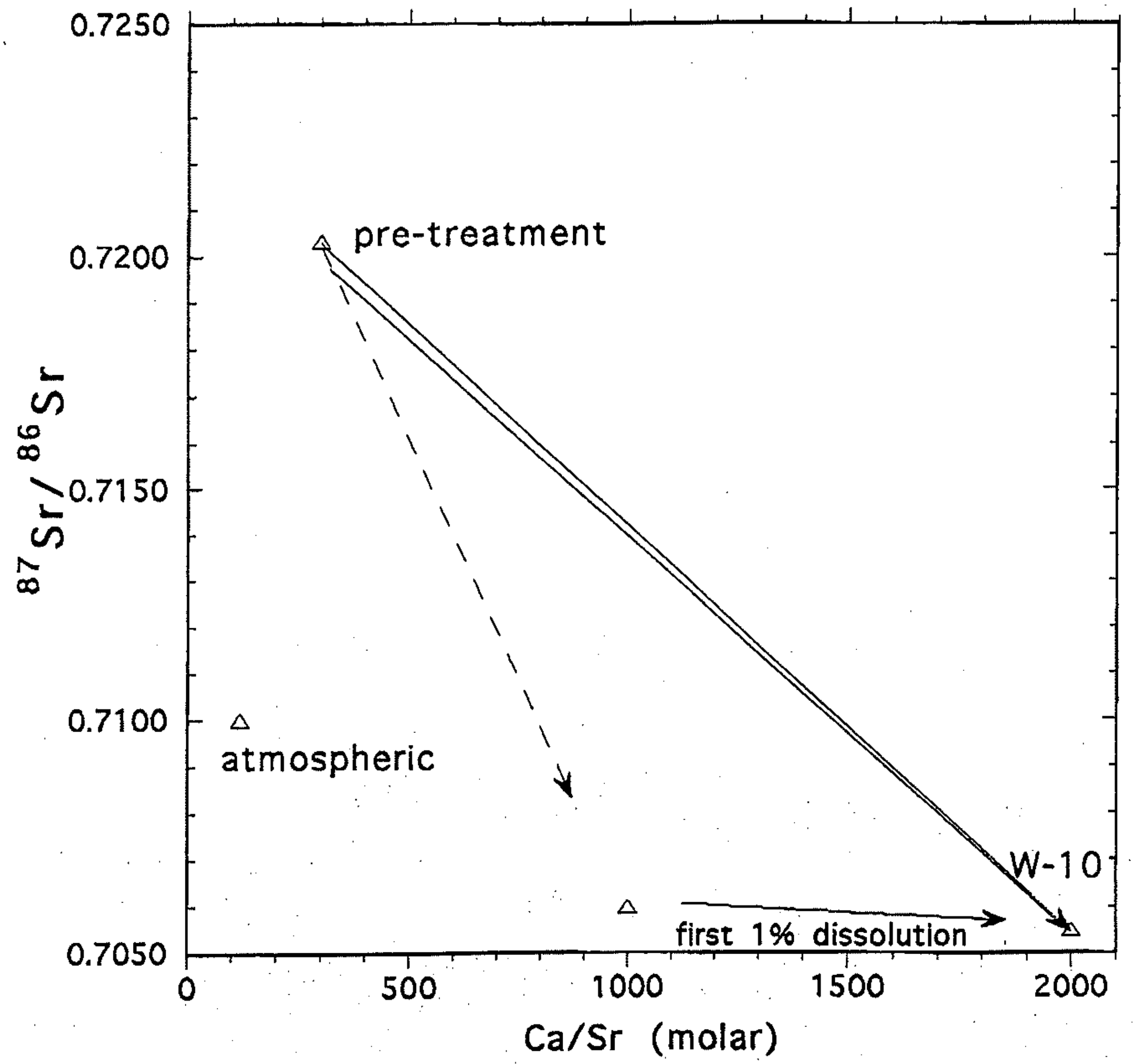

Potassium
Concentration (µeq/L)
Concentration (mg/L)
W2
W6
Water Year
0
20
40
60
80
100
0
1
2
3
4
1960
1965
1970
1975
1980
1985
1990
1995
2000


(a)
Aboveground nutrient pools (kg/ha)
0
20
40
60
80
100
120
140
1969
1973
1977
1981
1985
Year
Calcium
Nitrogen
Sulfur
Potassium
Magnesium
Phosphorous
(b)
Aboveground biomass and nutrient pools
(% of reference forest)
0
10
20
30
40
50
60
1969
1973
1977
1981
1985
Year
Ca
N
S
K
Mg
P
Biomass

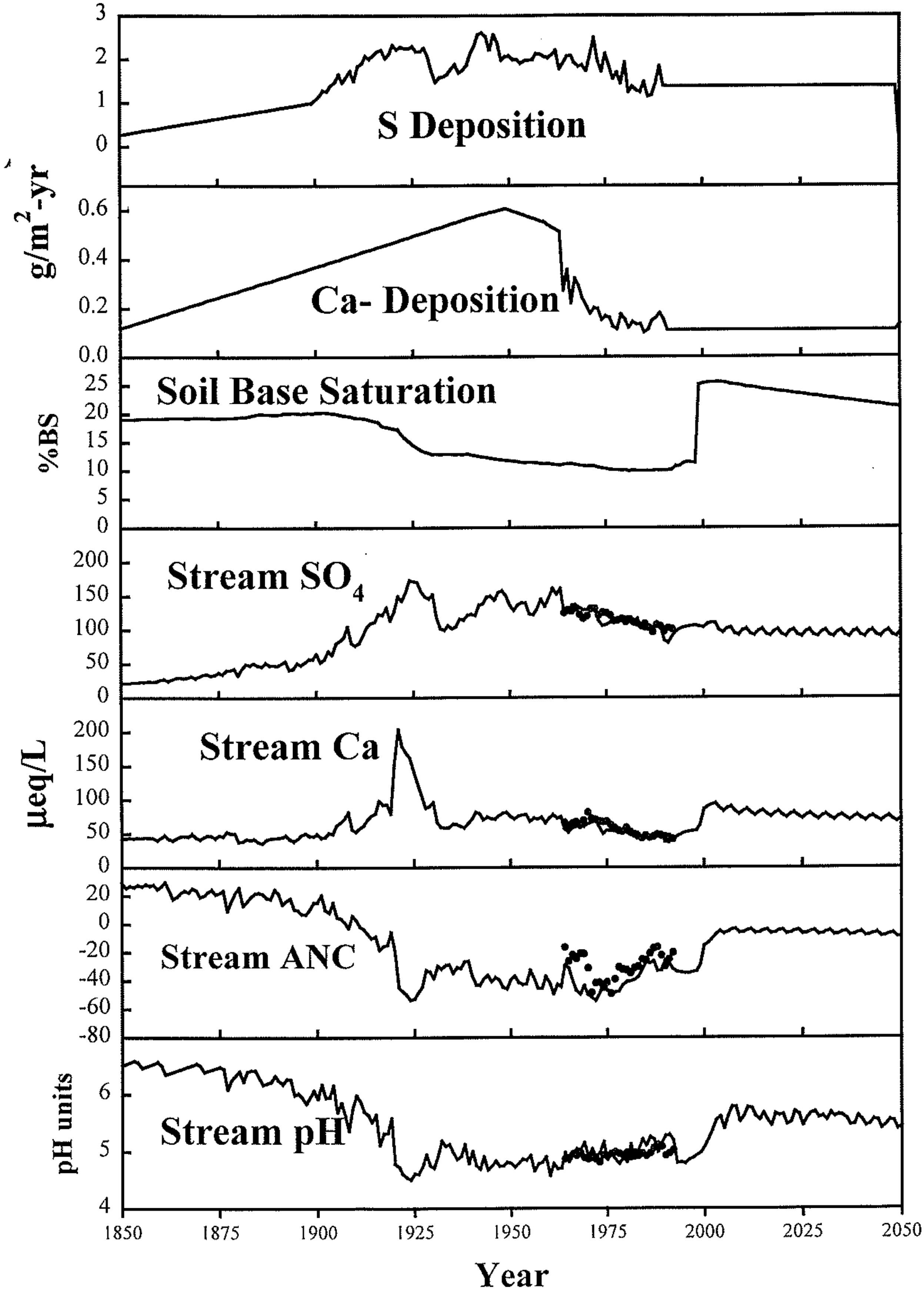
Calcium Manipulation Experiment (W1) (C. Johnson)

This fall a chemical manipulation study is planned for watershed 1(W1). Watershed 1 is 11.8 ha. In this study wollastonite ($CaSiO_3$), pelletized with a 4% lignosulfonate binder, will be applied by helicopter in an effort to replace the calcium that has been depleted from soil over the last 50 years due to inputs of acid rain (see figure). We hypothesize that through the regulation of the acid-base status of soil and drainage waters, inputs of calcium are a master variable which control the structure and function of the forest ecosystem. We anticipate that soil and stream acidity will decrease in response to the chemical treatment, thereby mitigating the effects of acid rain. We also expect that increases in soil pH, mediated by the adddition of wollastonite, will alter soil microbial activity, populations of soil biota and forest vegetation. Forty-five tons of wollastonite will be added to W1 to increase in base saturation of soil from approximately 10 to 19%. The wollastonite to be added has a distinctive calcium to strontium ratio and strontium stable isotope ratio which will enable us to track the fate of the added material (see figure). Detailed studies on the response of soil, soil water and groundwater, vegetation, microbial biomass and activity, soil invertebrates, stream water and aquatic biota to the wollastonite addition are being conducted. A series of plots for destructive sampling have been established adjacent to the watershed. Calculations have been made using the model PnET-BGC to predict the biogeochemical response to the chemical addition (see figure).





0.7250
0.7200
0.7150
0.7100
0.7050
$^{87}Sr/^{86}Sr$
pre-treatment
atmospheric
W-10
first 1% dissolution
0
500
1000
1500
2000
Ca/Sr (molar)



S Deposition
Ca- Deposition
g/m²-yr
Soil Base Saturation
%BS
Stream SO4
Stream Ca
µeq/L
Stream ANC
Stream pH
pH units
1850
1875
1900
1925
1950
1975
2000
2025
2050
Year

Soils at Hubbard Brook (C.E. Johnson)

Soils at the HBEF are generally well-drained Spodosols with sandy loam texture. All soils in the Experimental Forest are derived from glacial till deposited in the Wisconsinan glacial period, which ended ~14,000 yr ago. Because of the predominantly granitic parent materials, the soils are highly acidic, with pH generally less than 4.5 (and occasionally less than 3.0). Because of cool, humid conditions, an organic rich O horizon ("forest floor"), ranging from 2 to 20 cm in depth, lies above the mineral soil. This highly permeable layer allows rapid infiltration of water. Total depth of soil is highly variable. Along the ridgetops, bedrock outcrops are common, while on gentle slopes soil depths of several meters occur. The average depth of the pedogenic zone (to the C horizon or bedrock) is approximately 60 cm. The C horizon in many places is a low-permeability "pan" layer, restricting root development and water movement.

Like all Spodosols, the soils at Hubbard Brook show striking horizonation. Intense leaching of Al and Fe has created a gray E horizon below the O horizon. Redeposition of organic matter and metals below the E horizon results in a dark brown Bh and progressively redder Bs horizons. Hubbard Brook soils have rather high organic matter content – about 60% by mass in the O horizon, and 10% in the mineral soil. As a result, the mineral soil contains about 6 times the organic matter as the O horizon. Organic matter is the principal source of cation exchange capacity (CEC) in these clay-poor soils. However, because of the high acidity, base saturation is only about 10% in the mineral soil (~50% in the O horizon).

To sample the stony soils at Hubbard Brook, we developed a novel quantitative method, in which soil is excavated using a 0.707-m by 0.707-m template (area = 0.5 m^2). Soil is removed by layers: Oi + Oe horizons (as one sample), Oa horizon, 0-10 cm mineral soil, 10-20 cm, and 20 cm to C horizon or bedrock. All soil and rock is weighed in the field, allowing us to produce precise estimates of soil mass. Sub-samples of these layers are then analyzed for chemical properties, and nutrient pools computed from soil masses and nutrient concentrations. Additionally, samples are collected by pedogenic horizon from the pit faces. This method has been used in four "big digs" on watershed 5 (in 1983, 1986, 1991, and 1998) to examine clear-cutting effects, and on watershed 1 to characterize the soil chemical pools prior to the addition of wollastonite this fall.

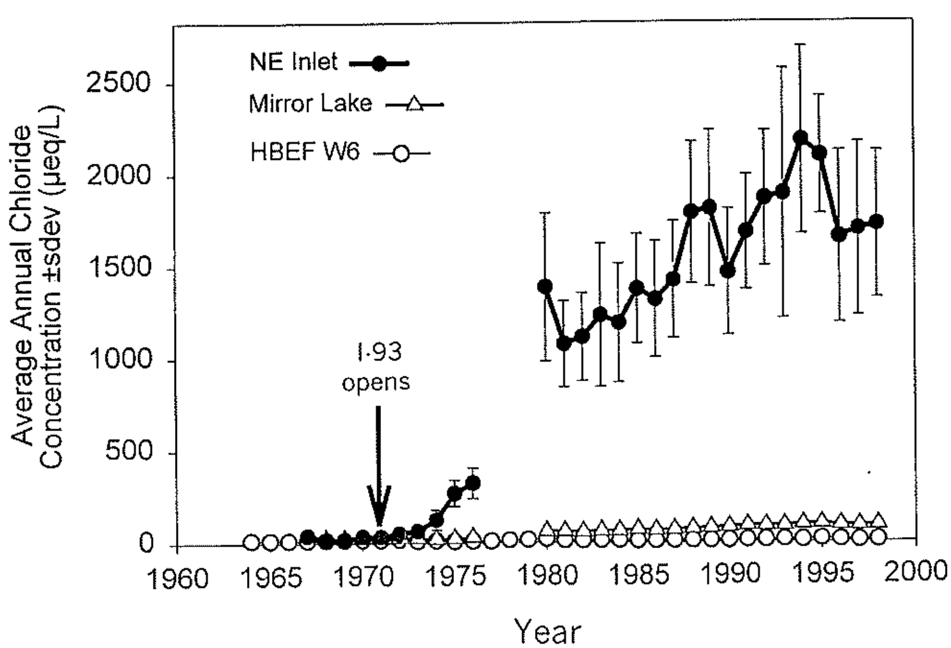
Grab samples of soils are also collected for monitoring of microbial biomass C and N, and respiration/nitrification incubation studies, led by Peter Groffman. These samples are collected approximately quarterly at sites near watershed 6. Other soil-related initiatives include the examination of the response of soils to Ca and Al additions in upper-elevation plots dominated by sugar maple (the "NUPERT" study, C. Eager); a study of the effects of soil freezing (Groffman, Driscoll, Fahey); an examination of long-term changes in soil C storage using soil bags (C. Driscoll); and the study of the chemical composition of soil organic matter (C. Johnson).

STOP 5   MIRROR LAKE

Mirror Lake Studies (D. Buso)

Samples of Mirror Lake and its three inlets have been collected as a part of the Hubbard Brook Ecosystem Study (HBES) since 1967. Mirror Lake is also the site for comprehensive hydrologic studies focusing on groundwater flow, conducted in cooperation with the USGS since 1978. In 1971, a section of Interstate Highway 93 (I-93), adjacent to Mirror Lake, was completed and opened for traffic. Within a year, there was a detectable increase in sodium and chloride in the water draining the northeast (NE) inlet to the lake, due to deicer salt application on the roadway. Since then, sodium and chloride concentrations have increased 100-fold in the northeast inlet and 3-fold in the lake. Groundwater wells near the lake also have been contaminated by salt. These findings are detailed in a recent paper by Rosenberry et.al (1999).

In 1999, several meetings were held between HBES cooperators, the NH State Department of Transportation and the US Geological Survey, to plan a new project involving road salt monitoring and mitigation at Mirror Lake. The proposed action involves a two-stage project: 1) modification of drainage systems on I-93 within the Mirror Lake watershed to decrease salt transportation to the lake; 2) substitution of potassium acetate for sodium chloride in deicer applications on I-93 within the watershed. Stage 1 would be enacted in year 2000 as part of a planned rehabilitation of the I-93 roadbed by the US Department of Transportation. Stage 2 would be conducted for a 5-year period starting in about 2005, after any effects of the physical improvements are quantified. Measurements to be taken using the existing monitoring equipment would include precipitation chemistry and deposition (wet and dry), streamwater chemistry and flow, lakewater chemistry, and groundwater chemistry and flow. This site is unique in New England for its long-term database and extensive hydrologic instrumentation.



Based on Rosenberry, et.al 1999. Water, Air, and Soil Pollution 109:179-206.

Pemigewasset-Merrimack River (K. Driscoll)

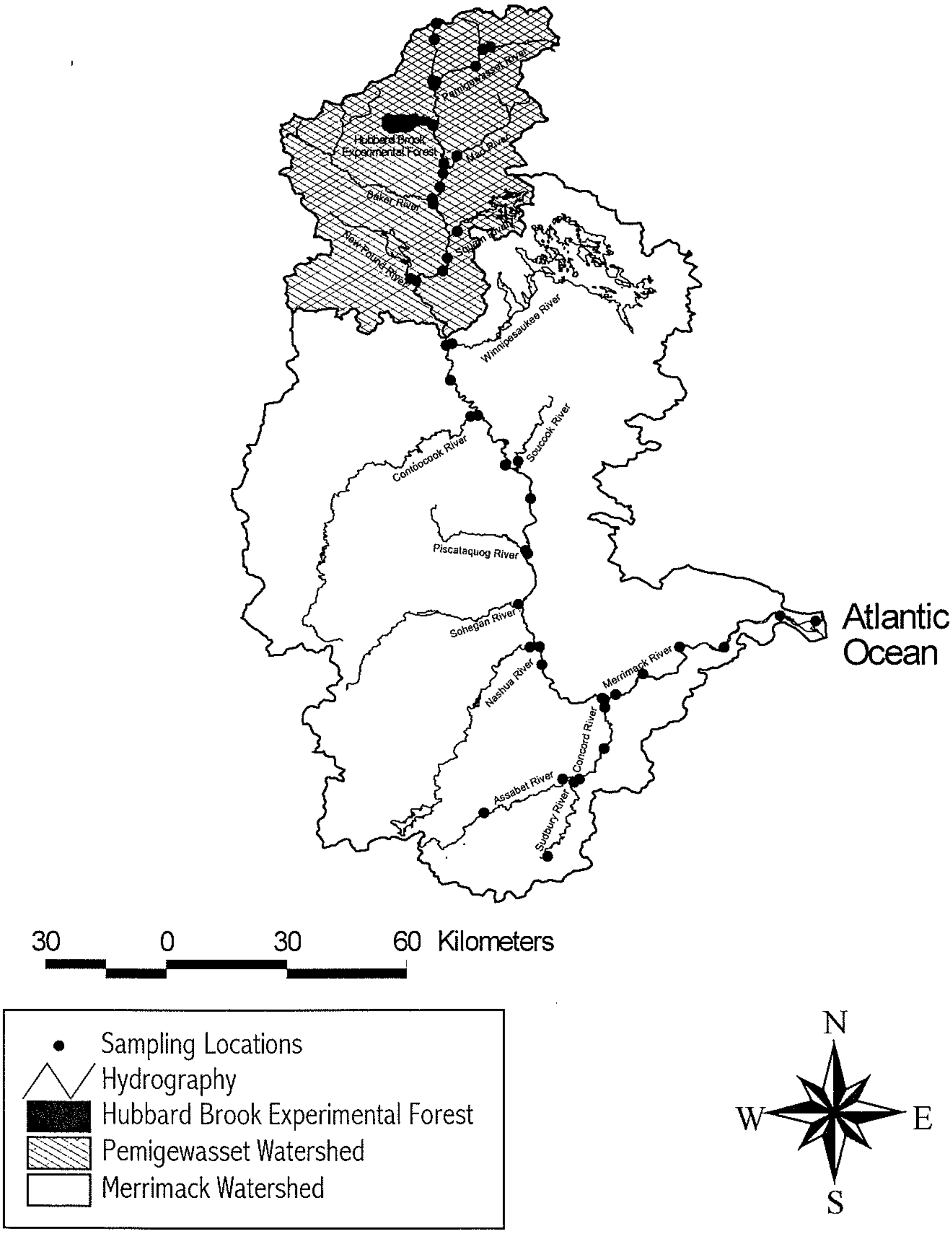
The streams from the Hubbard Brook Experimental Forest (3,000 ha) drain into the Pemigewasset River (watershed size = 265,000 ha). The Pemigewasset River then flows south through Plymouth, NH and converges with the Winnipesaukee River to create the Merrimack River (watershed size = 1,300,000 ha). The Merrimack River then flows south through the cities of Concord, Manchester and Nashua, NH. The River then crosses into Massachusetts and begins to flow east through Lowell, Lawrence and Haverhill, MA finally discharging into the Atlantic Ocean (see figure).

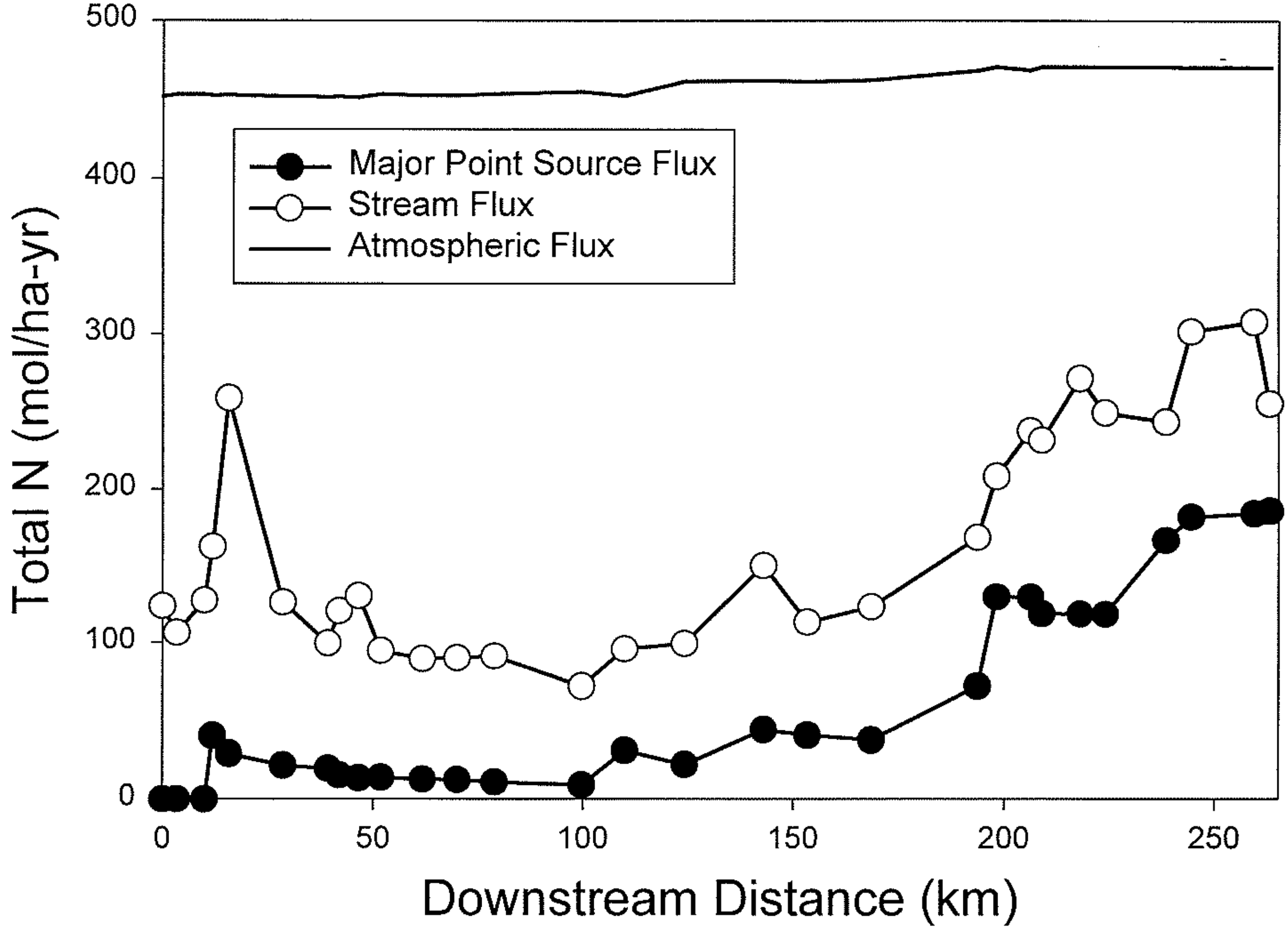
The objective of this study is to evaluate controls on surface water chemistry within the Pemigewasset-Merrimack River Basin. Water quality data from 51 longitudinal sites were collected for 16 months. Samples were measured for temperature, turbidity, dissolved oxygen, pH, selected trace elements and major solutes, including chloride, nitrogen fractions and total phosphorus.

A number of data layers, including a digital elevation model, hydrography, land use, census data, atmospheric deposition and information of point sources of discharge into the river have been organized in a geographic information system (GIS). Spatial water quality patterns are being empirically related to the GIS data layers using hydrologic data and monitoring data in order to gain a better understanding of longitudinal patterns in water quality measurements.

Results show marked longitudinal variation in the concentrations of most water chemistry parameters, from the headwaters of the White Mountains of New Hampshire to urbanized areas in southern New Hampshire and eastern Massachusetts (see figure). Large scale problems, such as the assessment of water quality on a large drainage basin are scientifically challenging and highly relevant to current policy issues.

Pemigewasset-Merrimack Watershed




Major Point Source Flux
Stream Flux
Atmospheric Flux
Total N (mol/ha-yr)
Downstream Distance (km)
500
400
300
200
100
0
0
50
100
150
200
250