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HYDROGEOCHEMICAL ASSESSMENT OF WATER IN FORESTED WATERSHEDS AT KEJIMKUJIK NATIONAL PARK: DISCHARGE RATES, CHEMICAL COMPOSITION, AND ION FLUXES

by

Shelagh Yanni

BScF., University of New Brunswick, 1992

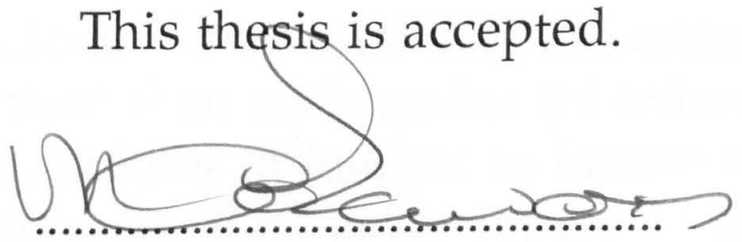
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ABSTRACT

Water quality has become an important factor for the future of our forests, aquatic life, and, in some cases, drinking water supplies. Forested watersheds provide several sources and sinks for nutrient flow en route to the stream: input from the atmosphere and geological sources; wet deposition passing through the forest canopy as throughfall and stemflow; water and nutrients passing through the forest floor and mineral soil; and some water and nutrients caught up in wetlands.

Kejimkujik National Park was chosen to study the patterns in stream water quality and watershed nutrient budgets for several watersheds, and to examine whether vegetation type, soil type, and landform associations were factors that affected the patterns. This study area has been the focus of the Long Range Transport of Air Pollutants Study across Canada since 1978, and has included a large-scale environmental monitoring program (the Kejimkujik Watersheds Study). The study included preparation of monthly and yearly summaries for watershed-based water and ion concentration fluxes and budgets, and a field study to ascertain dominant soil types, vegetation types, and landforms in each watershed.

It was found that watersheds at KNP do not vary much in terms of climate, vegetation type and topographical conditions. However, differences were found in water quality among watersheds with respect to the timing (and magnitude in some cases) of maximum and minimum concentrations of particular ions. Stream type (lake inlet versus lake outlet) was the main contributor to these differences, and also to the differences found for nutrient budgets among watersheds. Nutrient concentrations in the soil solutions differed among watersheds depending on the dominant vegetation types supported by the soils. Patterns emerged within soil profiles, specific to the August conditions when soils were sampled. Exchangeable cation concentrations followed the same patterns, but differences between watersheds were not as pronounced. Soils under softwood forest cover had higher turnover times (calculated as total soil ion concentration/streamwater ion concentration flux ratios) than soils under mixedwood forest cover, except for H and Al. The ranking of longest to fastest turnover times for each ion was consistent for both watershed cover types. In terms of forest nutrition, Mg was lost the fastest, then Ca and K.

Key Words: exchangeable cations, flux, hydrogeochemical, ion budgets, ion concentrations, Kejimkujik National Park, soil solution, streamwater quality, watershed, wetlands.

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S.D.Y.

CHAPTER 1

INTRODUCTION

Increasing concerns for the environment have prompted many studies that attempt to relate water quality to forest conditions. Previous experimental watershed studies have determined that physical, geochemical, and biological processes interact to produce changes in the chemical composition of water as it passes through the ecosystem (Swank and Waide 1988; Bormann and Likens 1979). For example, Swank and Waide (1988) made an observation for the Coweeta watersheds that "long term measurements of net nutrient budgets (bulk precipitation inputs minus stream exports) provide a quantitative means of characterizing integrated biogeochemical processes at the ecosystem level and of quantifying system-level changes due to human disturbance". The relationships between nutrient sources and sinks provide analytical tools for probing various aspects of the biogeochemistry of ecosystems as demonstrated for northern hardwoods (Bormann and Likens 1979).

Mechanisms controlling chemical yields from watersheds under natural conditions can be studied by quantitative examination of seasonal and annual trends within given watersheds (Johnson *et al.* 1969; Likens *et al.* 1977). This should also be true for comparisons of trends among watersheds that vary in biophysical characteristics such as forest cover, soil type and landform.

Biophysical characteristics of watersheds have been shown to be factors which influence streamwater chemistry (Haines and Swank 1988; Swank and Waide 1988; Lewis and Grant 1979). For example, elevation seems to be a controlling factor affecting streamflow and water chemistry: soils found at high elevations tend to be shallow, air and soil temperatures are low, and rates of precipitation and streamflow are high (Swank and Waide 1988). Altogether, the annual amplitude of monthly changes in streamwater chemistry are greater in the steeper, higher elevation watershed than in lower elevation watersheds (Swank and Waide 1988).

Vegetation type also affects water volume, quality and chemical composition as it passes through the ecosystem (Swank 1988). For example, the conversion of a hardwood stand to an eastern white pine stand ultimately increased evapotranspiration, reduced annual stream discharge, and reduced the export of dissolved nutrients (Swank 1988). In general, watershed-level nutrient retention and losses are affected by organic matter decomposition, vegetational nutrient uptake and storage. These processes are, in turn, affected by the seasons and by successional changes (Haines and Swank 1988).

Mineralogy and weathering rates of bedrock and till (soil parent materials) are additional factors that influence the chemical composition of streamwater (Swank and Waide 1988; Bormann and Likens 1979). Some elements are more abundant in the bedrock of some watersheds than in others. Atmospheric inputs (rain, snow, fog, dry deposition) are also important, and tend to add to the mineral outputs of the watersheds in many cases (Bormann and Likens 1979).

Concentrations of various chemicals in streamwater are predictable in terms of rate of streamflow and overall residence time of water within the

watershed (Johnson *et al.* 1969; Likens *et al.* 1977). Likens *et al.* (1977) concluded that streamwater chemistry stabilizes with increasing contact of water with the exchange surfaces as water travels toward the stream through the soils of the watershed.

With fast flowing water, streamwater ion concentrations tend to be highly variable, according to three categories: (*i*) substance concentrations may decrease with increasing discharge rates (ions so affected are HCO_3, NO_3, Ca, Mg, and Na); (*ii*) substance concentrations may show no trend with discharge (this is typically the case for NH_4, SO_4, dissolved organic phosphorus, and dissolved organic nitrogen) and; (*iii*) substance concentrations may increase with increasing discharge (this is the case for dissolved organic carbon, H, and phosphate P) (Lewis and Grant 1979).

Preliminary research into the water quality of three forested watersheds located in Kejimkujik National Park (KNP), Nova Scotia has revealed a correlation between streamwater chemistry and soil-vegetation complexes (Arp and Yanni 1992). These patterns differ among watersheds, and cannot be related to differences in precipitation chemistry. There is a need to further study the link between streamwater ion concentrations and soil-vegetation-landform characteristics, for the purpose of quantifying and examining this relationship in the context of nutrient budgets of forested watersheds at KNP.

OBJECTIVES

The objective of this thesis is to recognize patterns in streamwater quality and watershed nutrient budgets for several watersheds in or near KNP, and to examine whether vegetation type, soil type, and landform associations are factors that affect these patterns.

The study area is described throughout Chapter 2. In Chapter 3, hydrological fluxes in KNP (precipitation volumes, fog water deposition, and streamflow) are examined. Chapter 4 presents a detailed examination of the chemical composition of water in precipitation, throughfall, stemflow, and streamwater. Watershed ion budgets are presented and discussed in Chapter 5. Chapters 6 and 7 present KNP data for ion concentrations in the soil solution and the ion-exchange sites, according to watershed type. Total watershed ion concentrations in soil are estimated and relationships to streamwater outputs are discussed in Chapter 8. Chapter 9 deals with the soil C/N ratios. Final conclusions appear in Chapter 10.

GENERAL METHODS

The steps for completion of this research were as follows.

1. Gather precipitation, stream discharge, and streamwater chemistry data from nine watersheds located in or near KNP.
2. Prepare monthly and yearly summaries for watershed-based water and ion concentration fluxes and budgets.
3. Conduct a field study to ascertain dominant soil types, soil depth, litter depth, vegetation types, and landforms in each watershed.
4. Analyze soil samples for coarse fragment content, textural classes, organic matter content, total nitrogen, available nitrogen, water-soluble and ion-exchangeable Ca, Mg, K, Na, Al, Fe, Mn, and soil pH.
5. Compile existing information on forest cover (i.e. species, age, composition).

6. Compile existing landform information.
7. Compile existing information about wetland percentage and type of wetlands for each watershed.
8. Analyze water quality patterns related to dissolved organic carbon, calcium, magnesium, nitrate, and aluminum concentrations by evaluating differences, similarities, and seasonal trends with respect to individual watershed characteristics.

CHAPTER 2

STUDY AREA DESCRIPTION

LOCATION AND HISTORY

Kejimkujik National Park is located in southwestern Nova Scotia and is roughly 24 km east-west and 24 km north-south enclosing an area of 377 km^2 (Gimbarzevsky 1975) (Fig. 1). During the late 18th century, huge hardwoods dominated the uplands, while giant white pine (*Pinus strobus* L.) and other softwoods covered the slopes and lowlands. The ancient trees were cut for ship's masts and timbers. In later years, the spruce (*Picea* sp.) was pulped, land was cleared for farming, and hardwood was cut for firewood. The entire park has been affected by several types of disturbance (i.e., fire, harvesting, insect defoliation). Presently, the forests are less than 100 years old on average. The exceptions include a few groves of eastern hemlock (*Tsuga canadensis* (L.) Carr.) over 300 years old, and small isolated white pine stands along lakeshores and on islands. The entire park shows evidence of past burning with the last large fire occurring in 1928 (Environment Canada 1993).

A large scale environmental monitoring program was initiated at KNP (the Kejimkujik Watersheds Study) in 1978 in accordance with the Canada-wide Long Range Transport of Air Pollutants (LRTAP) Study. The KNP watersheds are exceptional in that they have features not present in the other LRTAP study areas: (*i*) the area is thought to be particularly sensitive

to the effects of acid precipitation on terrestrial and aquatic life as indicated by chronic streamwater pH depressions (Kerekes 1989), and; (*ii*) this area includes lakes with a wide range in colour and dissolved organic carbon contents.

Several studies have been conducted at KNP by a range of organizations to address the effect of atmospheric deposition on terrestrial and aquatic life (Elder and Martin 1989; Freedman *et al.* 1989; Kerekes and Freedman 1989; Kerekes *et al.* 1989; Percy 1989; Sirois and Summers 1989; Allen *et al.* 1992). Studies outside the park have also been done to understand the influence of climate and acidic deposition on ecosystems for Nova Scotia in general (Beattie and Whelpdale 1989; Hazlett and Foster 1989; Mahendrappa 1989; Underwood *et al.* 1989).

WATERSHED LOCATIONS

Several watersheds within and near the Park have been monitored for streamflow and streamwater chemistry (Fig. 1). Mersey River, Roger's Brook, and Moosepit Brook have been measured for streamwater discharge rate. Streamwater chemistry has been measured at Mersey River (below Mill Falls and below Kejimkujik Lake), Roger's Brook, Moosepit Brook, Atkin's Brook, Mount Tom Brook, Pine Marten Brook, Pebbleloggitch Lake, Grafton Brook, and Beaverskin Brook. In the course of this study, each watershed was categorized as to whether it was a lake inlet or lake outlet in order to separate influences on streamwater characteristics (Table 1).

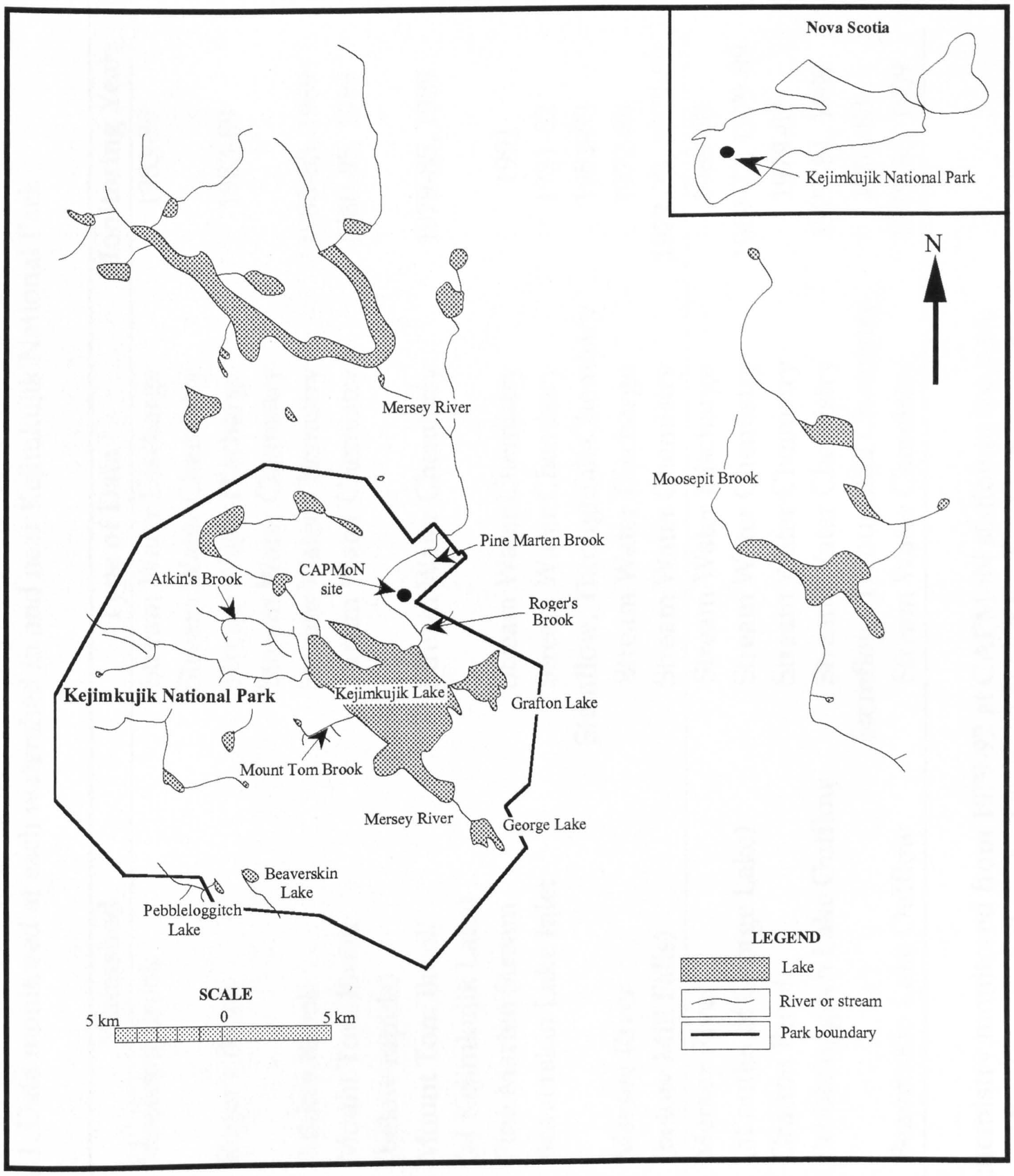


Fig. 1. Study areas located in and near Kejimkujik National Park, Nova Scotia.

Table 1. Data monitored at each watershed in and near Kejimkujik National Park

	Watershed	Type of Data *	Monitoring Years
Lake Inlets	Moosepit Brook	Stream Water Discharge	1983-89
		Stream Water Chemistry	
	Roger's Brook	Stream Water Discharge	1983-89
		Stream Water Chemistry	
	Atkin's Brook	Stream Water Chemistry	1980-85, 1989
	Mount Tom Brook (below rapids)	Stream Water Chemistry	1980-85, 1989
	Mount Tom Brook (at Kejimkujik Lake)	Stream Water Chemistry	1979-85, 1989
	Pine Marten Stream	Stream Water Chemistry	1991
	Beaverskin Lake Inlet	Stream Water Chemistry	1981-82
		Stemflow, Throughfall Chemistry	1981-83
	Mersey River (below Mill Falls)	Stream Water Discharge	1972-89
		Stream Water Chemistry	1972-73, 1979-89
Lake Outlets	Mersey River (at outlet of George Lake)	Stream Water Discharge	1969-89
		Stream Water Chemistry	1969-73, 1979-89
	Grafton Brook	Stream Water Chemistry	1979-89
	Pebbleloggitch Lake Outflow	Stream Water Chemistry	1979-84, 1989
		Stemflow, Throughfall Chemistry	1981-83
	Beaverskin Lake Outflow	Stream Water Chemistry	1979-85, 1989

Precipitation chemistry monitored from 1979-92 at CAPMoN station in the park

* data courtesy of Environment Canada, Monitoring and Evaluation Branch, Moncton, N.B.

PHYSIOGRAPHIC FEATURES

Geology

The biophysical survey done in the Park in 1975 by Gimbarzevsky identified the underlying bedrock as igneous and metamorphic rocks of the Paleosoic age, occasionally exposed along the river banks, lakes and road cuts. They consist mainly of granites, slates, schist and quartzites (Jones 1965). Devonian granite underlies the southwestern parts of the park, Halifax slates with quartzite occur in the north-east and south of Kejimkujik and Peskowesk lakes, and Goldenville greywacke occurs in the northwestern portion and southeast of Loon and Silver lakes (Fig. 2). Glacial movement during the Pleistocene period left behind glacial till, drumlins, and moraines (Fig. 3).

Climate

Climate parameters (e.g. precipitation volume of rain and snow, windspeed, etc.) were measured at a meteorological station in the park starting in 1966. A Canadian Air Pollutant Monitoring station (CAPMoN) was subsequently installed in 1979 to determine the status of atmospheric ion deposition (H, Ca, Mg, Na, K, Cl, SO_4-S, NO_3-N, NH_4-N).

KNP lies within the cool, humid temperate climate zone with a Maritime influence. There are, on average, high levels of precipitation (≈1400mm/year) and runoff (≈960mm/year), with discontinuous snow accumulation during the winter season. A summary of temperature and precipitation over 75 years is presented in Table 2. This information was required for the hydrological model (see Chapter 3).

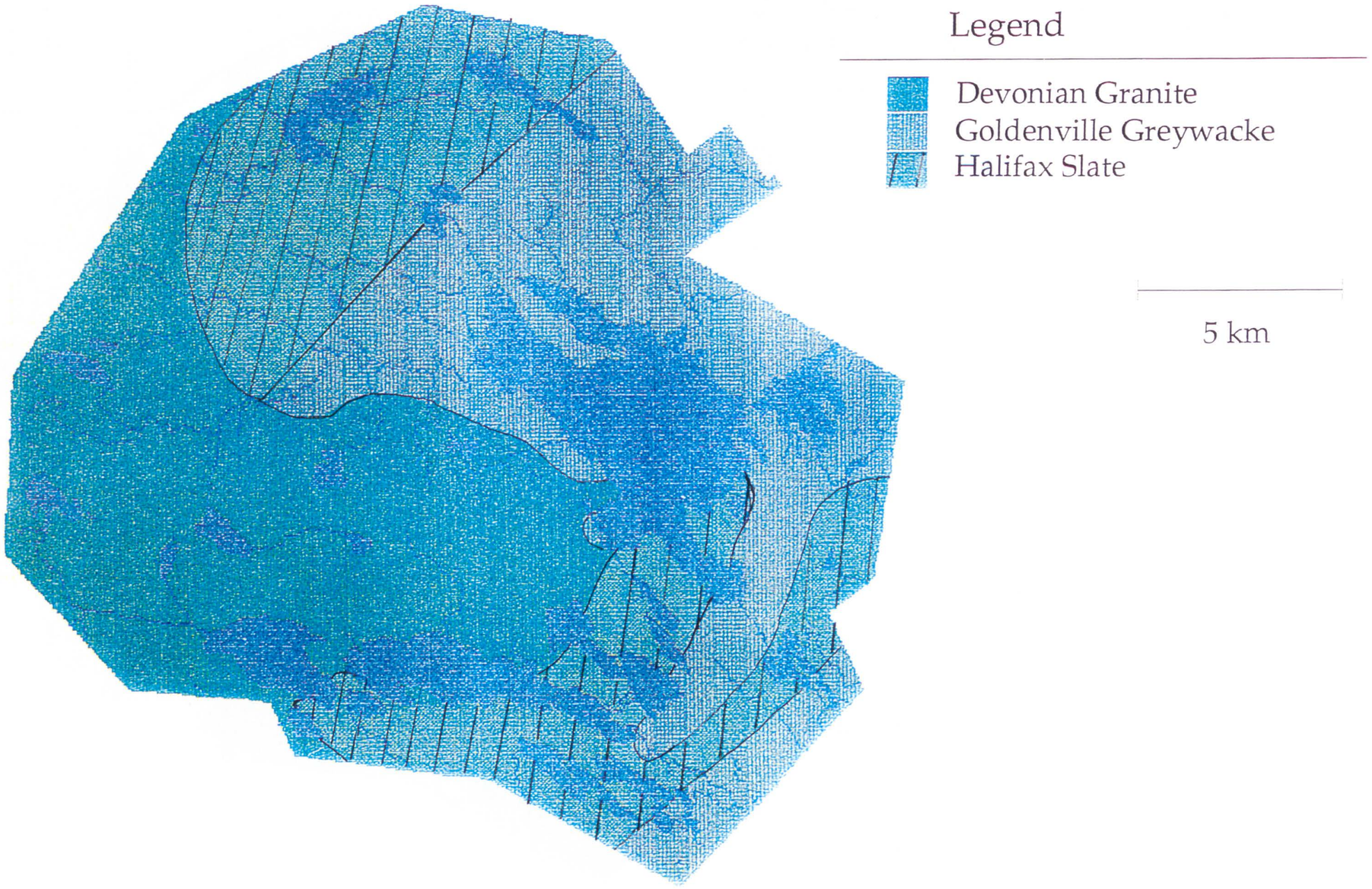


Fig. 2. Bedrock geology of Kejimkujik National Park (From Gimbarzevsky 1976).

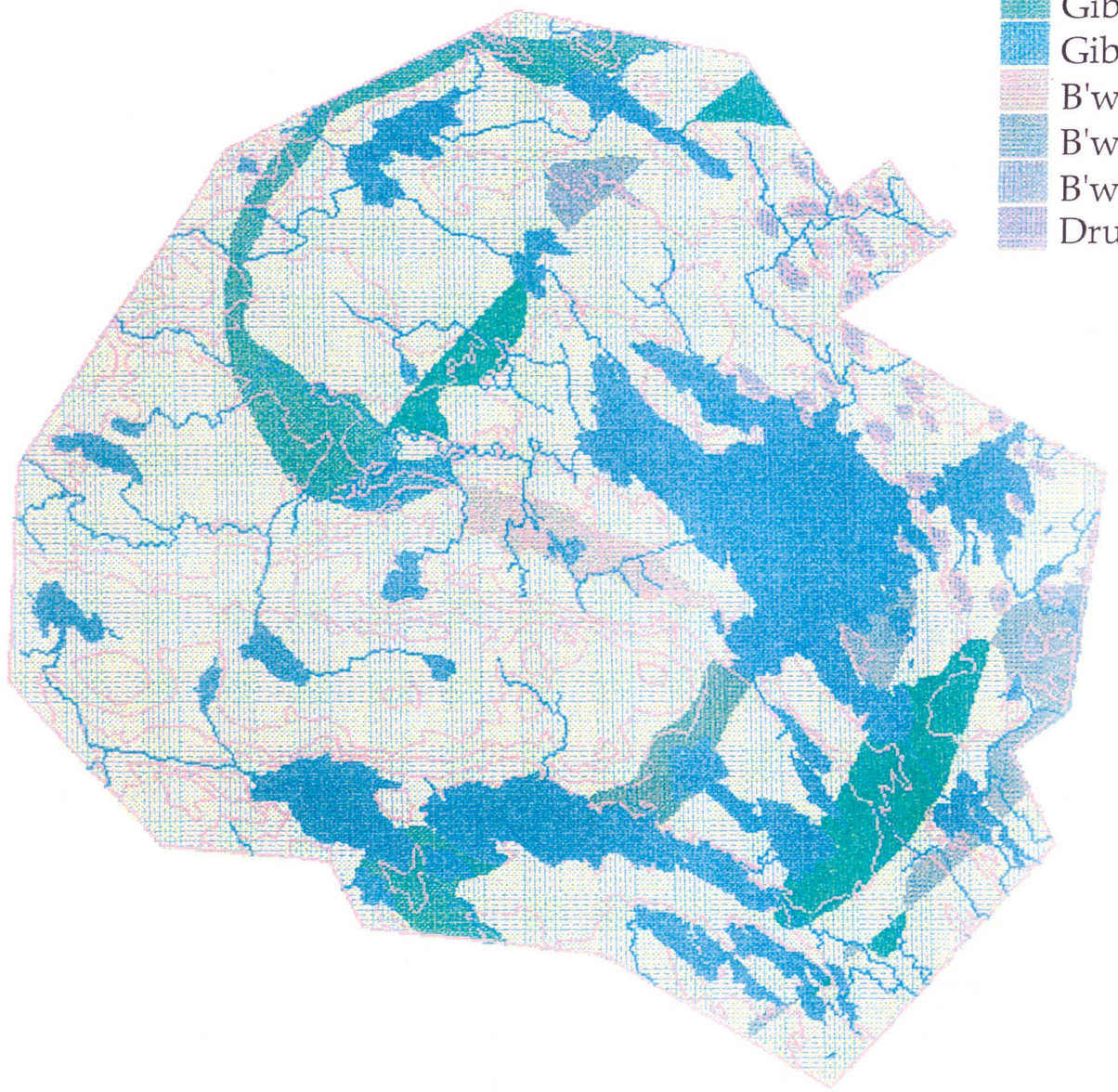


Fig. 3. Landform characteristics at Kejimkujik National Park (From Gimbarzevsky 1976).

Table 2. Average yearly temperature and precipitation for Kejimkujik National Park

YEAR	AVERAGE TEMPERATURE * (°C)	PRECIPITATION TOTAL * (mm)
1989	6.08	1361
1988	6.41	1474
1987	6.29	1266
1986	5.94	1421
1985	7.18	1302
1984	7.18	1329
1983	7.35	1065
1982	6.25	1331
1981	7.03	1538
1980	5.65	1226
1979	6.71	1742
1978	5.58	1184
1977	6.43	1655
1976	6.56	1462
1975	6.17	1000
1974	5.86	1475
1973	7.03	1225
1972	5.43	1541
1971	6.28	1477
1970	6.05	1347
1969	7.01	1367
1968	6.16	1214
1967	5.95	1368
1966	6.74	1083
1965	5.52	1095
1964	5.83	1457
1963	5.93	1477
1962	6.12	1247
1961	6.60	1413
1960	6.84	973
1959	6.33	1592
1958	5.86	1550
1957	7.10	1331
1956	4.87	1238
1955	6.33	1089
1954	6.17	1208
1953	7.49	1182
1952	6.53	818
1951	6.93	1228
1950	5.70	1175
1949	7.01	1128
1948	5.46	1350
1947	6.51	1222
1946	5.88	1165
1945	6.18	1116
1944	6.06	1122
1943	5.33	1322
1942	6.14	1323
1941	5.38	1304
1940	5.28	1232
1939	5.53	1174
1938	6.22	1327
1937	6.96	1027
1936	6.19	1428
1935	5.74	1285
1934	5.55	1311
1933	5.80	1530
1932	6.43	1174
1931	7.00	1220
1930	6.49	841
1929	6.09	1266
1928	5.89	1157
1927	6.06	1331
1926	4.68	1304
1925	5.28	1104
1924	5.45	1033
1923	4.03	1327
1922	5.53	1045
1921	6.07	1102
1920	5.41	1137
1919	5.87	1268
1918	5.27	1148
1917	4.70	1407
1916	5.50	1079
1915	5.79	977
1914	4.87	1059
Average	6.07	1261.46

Actual Data from Kejimkujik National Park

Data Predicted for Kejimkujik from Kentville data

* data courtesy of Environment Canada

BIOPHYSICAL FEATURES

A biophysical survey of the topography and soils was conducted and reported by Gimbarzevsky in 1975, and an inventory of the aquatic resources was conducted in 1970 and 1971.

Topography

The general topography of the park is a rolling till plain of glacial origin, sloping gently southeast. Approximately one-half of the area has an undulating topography, while nearly 30 percent consists of relatively level plains and depressional flats. The remaining 20 percent is made up of isolated knobs, elongated hills, or low ridges with relief differences below 25 metres (Gimbarzevsky 1975). The highest elevation within the park is 183 metres.

Soils

Soils are mainly podzolic sandy loams, with dark grey loams and peat frequently found in the wet areas (Fig. 4). Drainage ranges from well drained to very wet, with the very wet found in organic areas. A field study was conducted to fully describe the watershed soil characteristics, and will be discussed in more detail in Chapter 6.

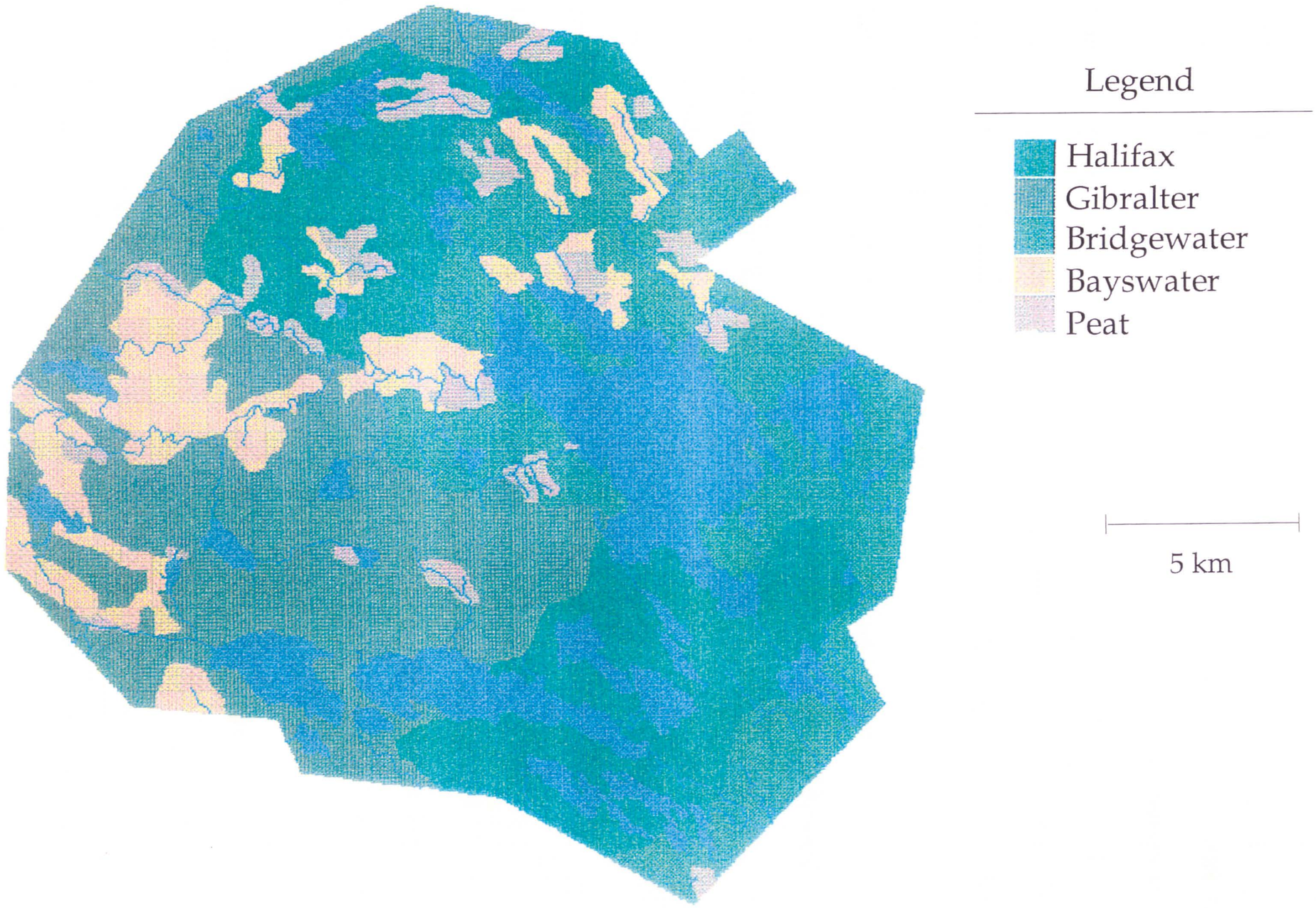


Fig. 4. Soil characteristics at Kejimkujik National Park (From Gimbarzevsky 1976).

VEGETATION

Forest Cover Types

In general, KNP is 94% forested, with 75% of the forest comprised of mixed hardwood-conifer stands, 21% coniferous stands, and 4% hardwood stands (Gimbarzevsky 1975). Softwood stands include a few groves of eastern hemlock and small isolated white pine stands along lakeshores and islands. Hardwood stands are located on rich, well drained glacial deposits (drumlins) and are usually two-layered: yellow birch (*Betula alleghaniensis* Britton) and sugar maple (*Acer saccharum* Marsh.) forming the upper canopy and younger trees of the same species forming the lower canopy. Mixedwood stands result from recent disturbances (Environment Canada 1993).

The field study included measurements of forest cover, ground vegetation and site classification at each soil site. The general forest characteristics for each watershed were also noted. This information is summarized in Table 3. The past effects of forest fires, logging and agricultural development has resulted in a wide variation in species composition (Gimbarzevsky 1975). As a result, fourteen forest cover types have been defined for the park. The following definitions describe the types that occur in the watersheds studied.

Pine Marten Brook and Moosepit Brook watersheds were representative of the SFP-MB (Spruce, fir, pine-maple, birch) type. This is the largest forest cover type in the park. The main species are red spruce (*Picea rubens* Sarg.), balsam fir (*Abies balsamea* (L.) Mill.), white pine, red maple (*Acer rubrum* L.) and white birch (*Betula papyrifera* Marsh.), growing as heterogeneous mixtures of heights, ages and densities. It is found on dry to

Table 3. Field data results for forest cover and ground vegetation

Watershed	Forest Cover †	Species	Height	Age	Ground Cover (in order of abundance) ††
Mount Tom Brook	wP, rM, bS, rO	bS	9	78	40, 7, 72, 32, 9, 14, 60, 31, 55, 59, 65, alder, bF understory
West Ridge		wP	10, 10.5	48	very rocky soil, but roots grow deep into soil
		rM	12		
Mount Tom Brook	rO, wP, rM, bS, wB	rO	14.5		72, 7, 32, 60, 14, rO seedlings
East Ridge		rM	11.5		not as rocky as front ridge, well drained, matted mor but
		bS	9		H horizon missing.
		wP	12.5		
Atkins Brook	rO, bS, rM, bF	rO	17.5,15.5		7, 9, 60, rM, 35, 24, 15, 55, 43, 62, 35 (openings), rO seedlings
North Ridge		bS	14,12		small pockets of bS beside grasses beside brook
		wP	11.5		more open and rockier than south ridge
		rM	15.5		
Atkins Brook	wP, bS, rO, bF (understory), rM	rM	13		7, 9, 60, rM, 35, 24, 15, 55, 67
South Ridge		bS	14, 18	54	mound and pit
		rO	16		
		wP	12	50, 31	
Pine Marten Brook	Be, rM, bF, rO, stM				55, 18, rM, 20, 60, 1, 64, 44, 22, 68, 63, 52
Top Ridge					Be, wP, bF seedlings, bF understory (light)
Pine Marten Brook	bF, He, wB, wP, rS, rO, stM				mostly litter, 31, mosses
Low Ridge					matted forest floor, well-rapidly drained
Pebbleloggitch Lake	wP, rM, rO	wP	18.5		pine needles + 60, rM, 8, 26, 72, 55, 22, 7, 35, 68, 73
		rM	16.5		witch hazel was abundant understory approx 3m height
		rO	15		
Roger's Brook	He, sM, Be, rS, wB, rO	He	20, 20		34, 20, 55, 22, 57, 67, 59, 60
Hemlock Ridge		sM	23		
		rO	20		

Table 3. (Continued)

Watershed	Forest Cover †	Species	Height	Age	Ground Cover (in order of abundance) ††
Roger's Brook	wP, rS, gB, tA, ltA, bS	rS	18		9, 55, 15, 22, 7, 74, 70, 20, 16, 65
Pine Ridge		wP	18,19,18		bF understory
		tA	25		
Beaverskin Brook	rM, wP, bS, bF	wP	12.5	27	55, 65, 7, 9, 32, 49
Ridge		bS	10,9		Schreber's moss mat, steep slope
		rM	9		
		bF	4		
Moosepit Brook	bS, eL, rM, wP, bF	bF	11,9	65	59, 9, 35, 49, 55, 76, 16, 11, 68, 60, 64, 21, 20, 15, 67, 47
Forested		bS	10,6	24	ants present
		rM	6.5		very wet, grassy, sphagnum by brook, cut around 8-10 years ago
Moosepit Brook	bS, rM, He	bF	15	63	7, 72, 32, 49, rM and gB seedlings
Clearing		rM		8-10	open ridge, old cut, ants present, bF, bS, wP understory
		wP		8-9	about 1-2m height

† abbreviations are defined in Appendix I

†† ground vegetation corresponding to numbers in Appendix II

fresh, moderately coarse bouldery till, mainly in the central, upland and southwest corners of the park. The ground vegetation consists of *Pteridium aquilinum* var. *latiusculum* as a dominant species, growing with *Vaccinium angustifolium, Kalmia angustifolia* and *Cornus canadensis* (Gimbarzevsky 1975). Moosepit Brook is predominantly softwoods, and Pine Marten Brook is a mixedwood forest.

Atkin's Brook and Beaverskin Brook can be classified under the SFP-MOB forest cover type (Spruce, fir, pine with maple, oak and birch). This type occurs throughout the park and is usually associated with previously cut or disturbed areas. The ground vegetation consists mainly of *Pteridium aquilinum* var. *latiusculum, Vaccinium angustifolium, Kalmia angustifolia* and *Cornus canadensis* (Gimbarzevsky 1975). Atkin's Brook watershed has an even mixture of the softwood and hardwood species (mixedwood), whereas Beaverskin Brook is predominantly softwoods (72% softwoods) (Percy 1989).

Roger's Brook watershed is representative of the SHP-MB type (Spruce, hemlock, pine with maple and birch). The predominant species in this watershed are softwoods. Ground vegetation in this cover type is usually a *Humus-Bryophyte-Pteridium* association.

Pebbleloggitch Lake watershed, on an area basis, is only 48% coniferous species (Percy 1989). It is a PS-MB (Pine, spruce with maple and birch) forest cover type which results from disturbance (selective logging). The ground vegetation is dominated by the *Pteridium* association.

Mount Tom Brook watershed is classified as a MOB-PS type (Maple, oak, birch with pine and spruce). This watershed is mainly mixedwood forest. The ground vegetation is dominated by the *Pteridium* association.

Grafton Brook watershed is a predominantly hardwood forest covering several forest cover types. The main species are maple, oak, birch, spruce, hemlock, pine and beech. Ground cover vegetation include the *Dryopteris, Humus-Bryophyte,* and *Pteridium* associations.

Mersey River (below Mill Falls) tends to have a larger softwood component than Mersey River (below Kejimkujik Lake). Most of the forest cover types occur in these large watersheds, with varying ground vegetative cover.

Wetlands

There are extensive fens, bogs, and pyrogenic heath-dominated communities (Kerekes *et al.* 1989). Wetlands were identified using maps supplied by the Canadian Wildlife Service and consist of bogs, shrub swamps and grassy meadows. Wetland locations and percentage of wetlands in the watersheds are presented in Table 4.

Table 4. Summary of site characteristics

WATERSHED	AREA (ha)	ELEVATION† (m)	FOREST COVER‡ TYPE	GROUND COVER‡ Plant Community Associations	SOIL pH*	STREAM TYPE	WETLAND VEGETATION** Size (ha)	%	Vegetation Class	Site Type	SHORELINE WETLANDS** Lake Shoreline (%)	Stream Shoreline (%)	WATER RETENTION TIME (years)
Lake Inlets													
Moosepit Brook	1770	150-100	SFP-MB	*Pteridium*	3.2-5	lake inlet	2.1	<1	Bog	Upland Lakeside	-	20	-
Roger's Brook	874	120-90	SHP-MB	*Humus-Bryophyte-Pteridium*	4-4.6	lake inlet	3.5	<1	Shrub Swamp	Upland Streamside	-	40	-
Atkin's Brook	1360	140-90	SFP-MOB	*Pteridium*	3.3-5.1	lake inlet	147	11	Bogs, Shrub Swamps, Meadow	Upland Streamside	-	45	-
Mount Tom Brook	1020	200-90	MOB-PS	*Pteridium*	3.7-4.8	lake inlet	30.2	3	Shrub Swamps, Bog	Upland Streamside	-	40	-
Pine Marten Brook	130	120-90	SFP-MB	*Pteridium*	3.1-4.9	stream inlet	3.5	3	Bog	Upland Streamside	-	-	-
Mersey River (below Mill Falls)	29500	260-90	SFPH with MOBBe	various	-	lake inlet	53.3	<1	Bogs, Meadows, Shrub Swamps	Upland Streamside	-	2	-
Lake Outlets													
Mersey River (below Kejimkujik L.)	84200	260-90	MOBBe with PSH	various	-	lake outlet	0.9	<1	-	Upland Lakeside	25	0	0.2
Grafton Brook	5300	120-90	MOB-Be, SFP-MOB, SHP-MOB	*Dryopteris, Humus-Bryophyte, Pteridium*	-	lake outlet	2.6	<1	Bog	Upland Lakeside	20	0	0.19
Pebbleloggitch	200	140-120	PS-MB	*Pteridium*	3.3-5.3	lake outlet	116	58	Bog	Upland Lakeside	50	50	0.4
Beaverskin Brook	60	140-110	SFP-MOB	*Pteridium*	3.2-4.7	lake outlet	16.6	28	Bogs, Meadow, Shrub Swamp	Upland Streamside	0	45	1.16

† taken from topographic map
‡ Taken from field data and Gimbarzevsky (1975), abbreviations defined in Appendix III
* Laboratory analysis
** Canadian Wildlife Service wetland maps

HYDROLOGY

Kejimkujik watersheds are unique from other watersheds studied because of the highly organic waters not included in other studies (Elder and Martin 1989). It is important to study the effects of acid precipitation on such ecosystems in order to make comparisons to areas not under investigation that also have highly organic systems.

Lakes and rivers cover 1/5th of the 381 square km park and almost all flow into the Mersey River. The waters have few natural minerals because of unyielding slate and quartzite parent material. The lowest levels of calcium in North America are found in these waters, thus biological productivity in water is generally low. Coloured (brown) waters result from water picking up dissolved organic substances such as tannins flowing through bogs. Clear water lakes result from springs and runoff. The chemistry between the clear and brown waters is similar except for pH levels but the brown waters are more productive (Environment Canada 1993).

Streamwater discharge has been gauged since 1966 for Mersey River above and below Kejimkujik Lake. Moosepit Brook (located outside the park) and Roger's Brook have both been monitored for streamwater discharge. Streamwater chemistry was measured directly and analyzed using the methods employed by Kerekes *et al.* (1986a). There are plans to gauge other streams in the future.

Studies to date for the Kejimkujik Watersheds Study have largely included hydrogeochemistry and biophysical descriptions, and a few comparisons among watersheds. Watershed ion budgets have not yet been studied.

At the onset of this study, water chemistry and stream discharge data

were available from 1969 on. These data, however, were not yet summarized. In addition, information about specific soil types within watersheds has not been studied or documented. At the watershed level in KNP, streamwater chemistry has as yet not been studied in relation to forest cover and soil type.

CHAPTER 3

HYDROLOGICAL FLUXES AT KEJIMKUJIK NATIONAL PARK

INTRODUCTION

A forest modelling study was conducted to predict water fluxes through upland forest soils at KNP. This was done by making use of a forest hydrology model (ForHyM, Arp and Yin 1992). This model addresses all major water fluxes through forests (throughfall, forest floor percolate, soil percolate, surface runoff, interflow, streamwater flow, groundwater flow, interception, evapotranspiration, snowmelt) (Fig. 5). Monthly mean air temperature, monthly rain and snow volumes are used as input. Other data requirements are limited to latitude, proportions of coniferous and deciduous trees in the forest, thickness of each soil layer (forest floor, soil and subsoil), and clay fraction (or texture) of each mineral soil layer. Parameter calibration is applicable across sites, usually without further modification. The model successfully reproduces available data on throughfall, snowpack, forest floor percolate, soil water content, and streamflow from a deciduous and a coniferous forest.

Compared to other models, ForHyM has low data requirements, yet provides reasonable estimates for all major hydrologic fluxes through forest ecosystems. The trade-off associated with low data requirements is that the model, like other mixed models, is not strictly mechanistic, requires some

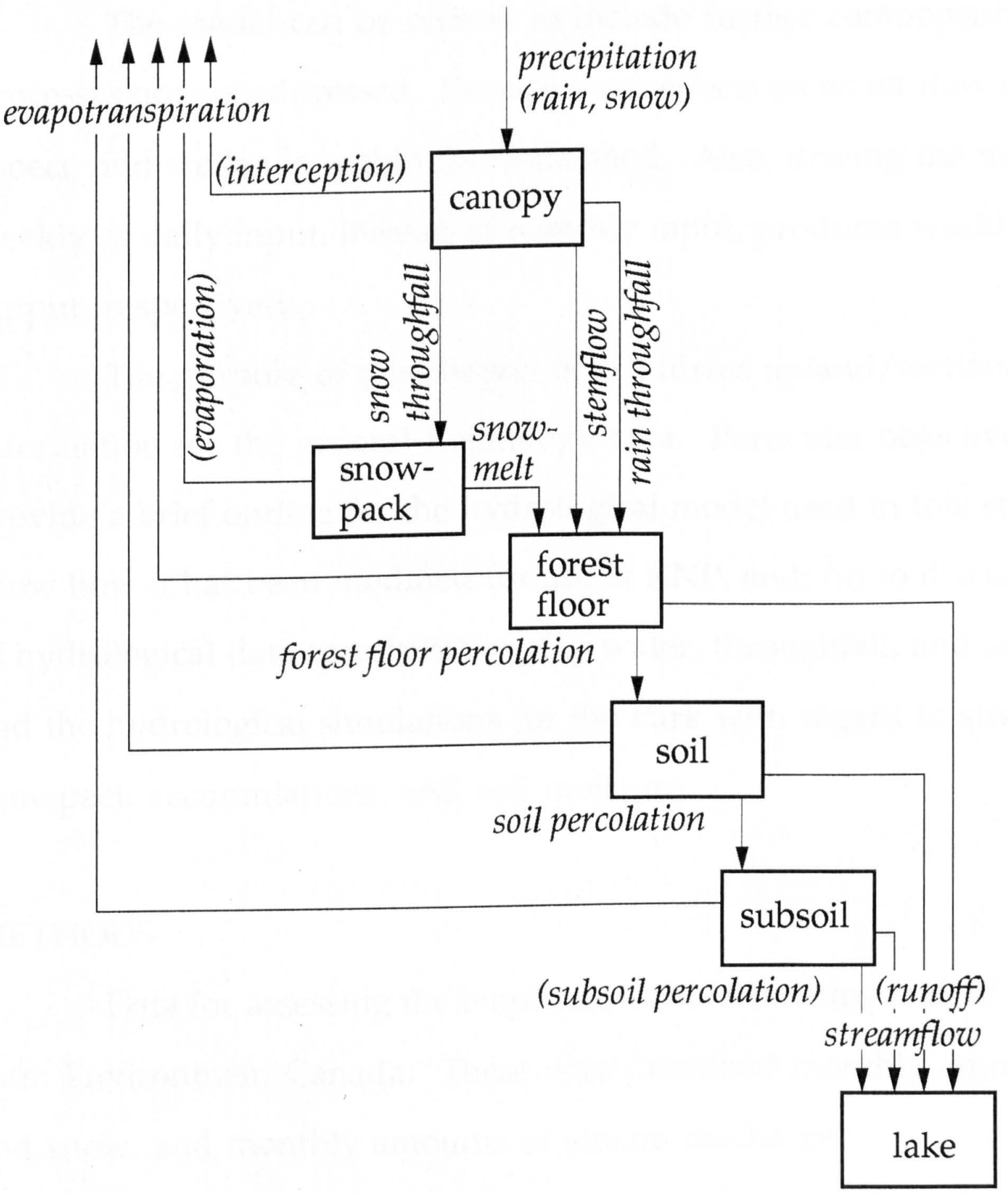


Fig. 5. Flowchart for the forest hydrology model ForHyM (From Arp and Yin 1992).

empirical assumptions about water fluxes, and requires measured flux data for parametrization.

The model can be refined to include further components and processes not yet addressed. Examples are effects on water flow of slope, aspect, and wetlands within the watershed. Also, driving the model with weekly or daily input, instead of monthly input, produces weekly or daily output, respectively.

The purpose of this chapter is to address upland/wetland water flux information for the general Kejimkujik area. Particular objectives are: (*i*) to provide a brief outline for the hydrological model used in this study, and to show how it has been modified for use at KNP, and; (*ii*) to discuss the results of hydrological data (precipitation, fog water, throughfall, and streamflow) and the hydrological simulations for the Park with regard to streamflow, snowpack accumulations, and soil moisture.

METHODS

Data for assessing the biophysical characteristics at KNP were obtained from Environment Canada. These data described monthly amounts of rain and snow, and monthly amounts of stream discharge.

Precipitation has been measured at KNP from 1966. Pre-1966 records (1914-1965) for KNP data were reconstructed from Kentville Weather Station data using a regression equation for the years 1914-1965 (Table 2) (Yanni 1992).

Data input requirements for the ForHyM model are outlined in Table 5. Arp and Yin (1992) and Yin and Arp (1994) provide a more detailed description of the methods used for hydrological flux assessments. These assessments include simulations for fog contributions (Yin and Arp 1994),

Table 5. Data input and water budget summary for the application of the forest hydrology model ForHyM for three streams in or near the Kejimkujik National Park in Nova Scotia

	Whiteburn Brook	Moosepit Brook	Mersey River
Latitude (north)	44°21'	44°28'	44°18'
Longitude (west)	65°03'	65°03'	65°20'
Area (ha)	NA*	1670	29500
Rain effect	Yes	Yes	Yes
Forest coverage	0.94	0.94	0.94
Deciduous:coniferous	50:50	50:50	50:50
Rooting habit	Medium	Medium	Medium
Forest floor depth (cm)	5	5	5
Mineral soil: depth (cm); texture	53; sandy loam	53; sandy loam	53; sandy loam
Subsoil: depth (cm); texture	70; loamy sand	70; loamy sand	70; loamy sand
Recorded precipitation (mm/yr)	1376	1298	1407
Recorded streamflow (mm/yr)	843	825	927
Record duration (yr)	1984-1987	1981-1988	1968-1989
Simulated fog water input (mm/yr)	106	102	97
Simulated streamflow (mm/yr)			
No fog	699	650	766
With fog	894	808	927

water received through fog drip, and water not lost from the area because of reduced evapotranspiration during periods of fog and mist.

Streamwater discharge data were available for three streams: Whiteburn Brook, Moosepit Brook, and Mersey River (two locations).

Roger's Brook lacked consistent monitoring of discharge as seen for mean annual water budget calculations (Fig. 6).

The calculation for discharge was computed as follows:

$$\text{Discharge (mm/month)} =$$

$$\text{Monthly } \Sigma \{ [\text{daily monitored discharge } (m^3/\text{sec}) * 60 * 60 * 24] * [1/DA(\text{ha})] \}$$

$$* [1 \text{ ha}/10000 \text{ m}^2] * [1000 \text{ mm}/1\text{m}]$$

Where DA = drainage area in ha

Average cumulative discharge rates for monitored basins were used to estimate mean monthly and annual streamwater budgets for streams that were not monitored (Fig. 7). Monitored averages were obtained from Moosepit Brook and Mersey River (below Mill Falls).

RESULTS AND DISCUSSION

Precipitation

Precipitation rates are presented in Table 2, and mean monthly and total cumulative precipitation (mm) are presented in Fig. 8. Precipitation volume in the form of rain and snow reached their highest levels during winter and spring. The least amount of precipitation was during late summer (Fig. 8).

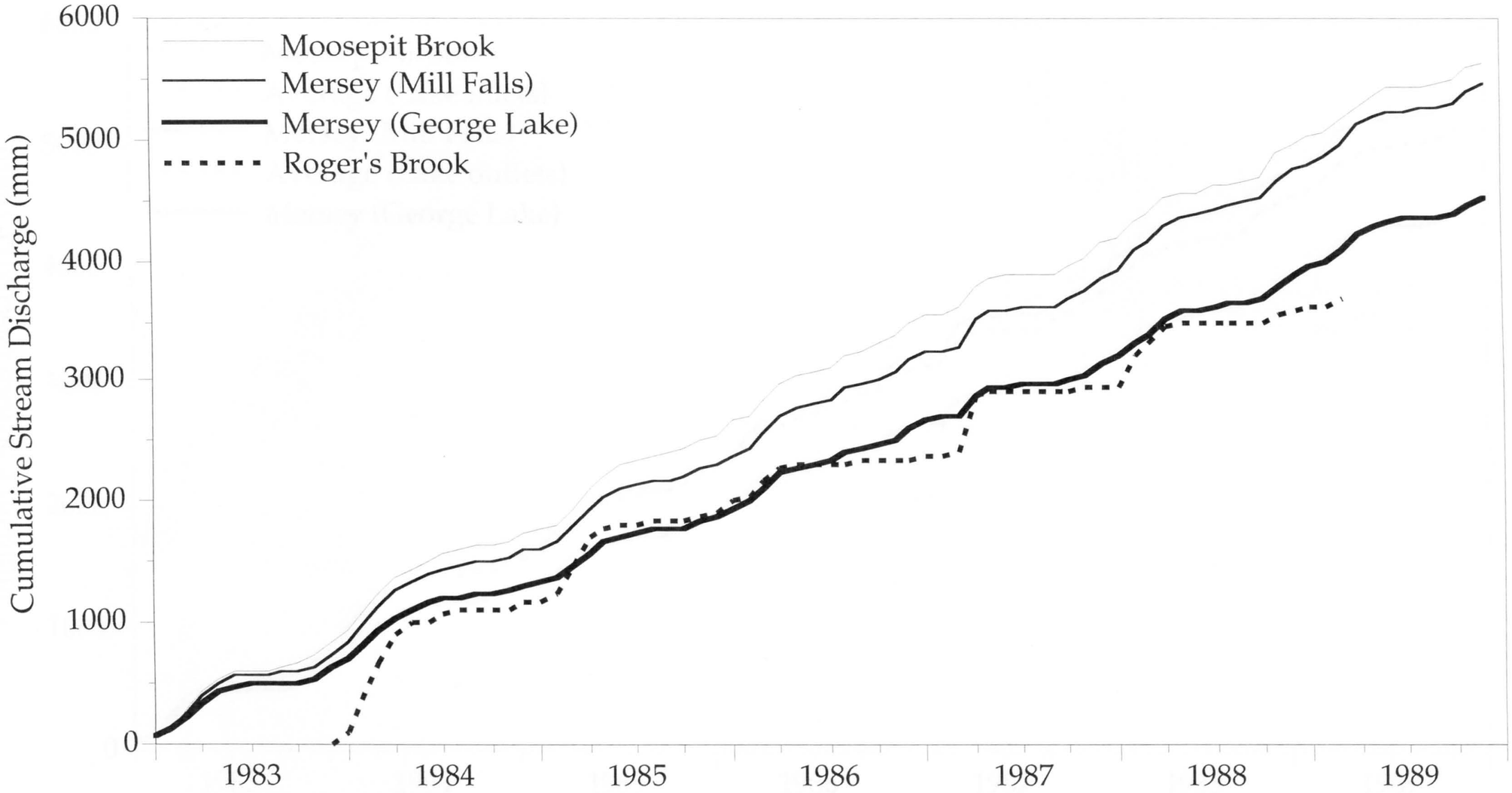


Fig. 6. Cumulative stream water discharge (mm) for monitored streams in and near Kejimkujik National Park. Data courtesy of Environment Canada.

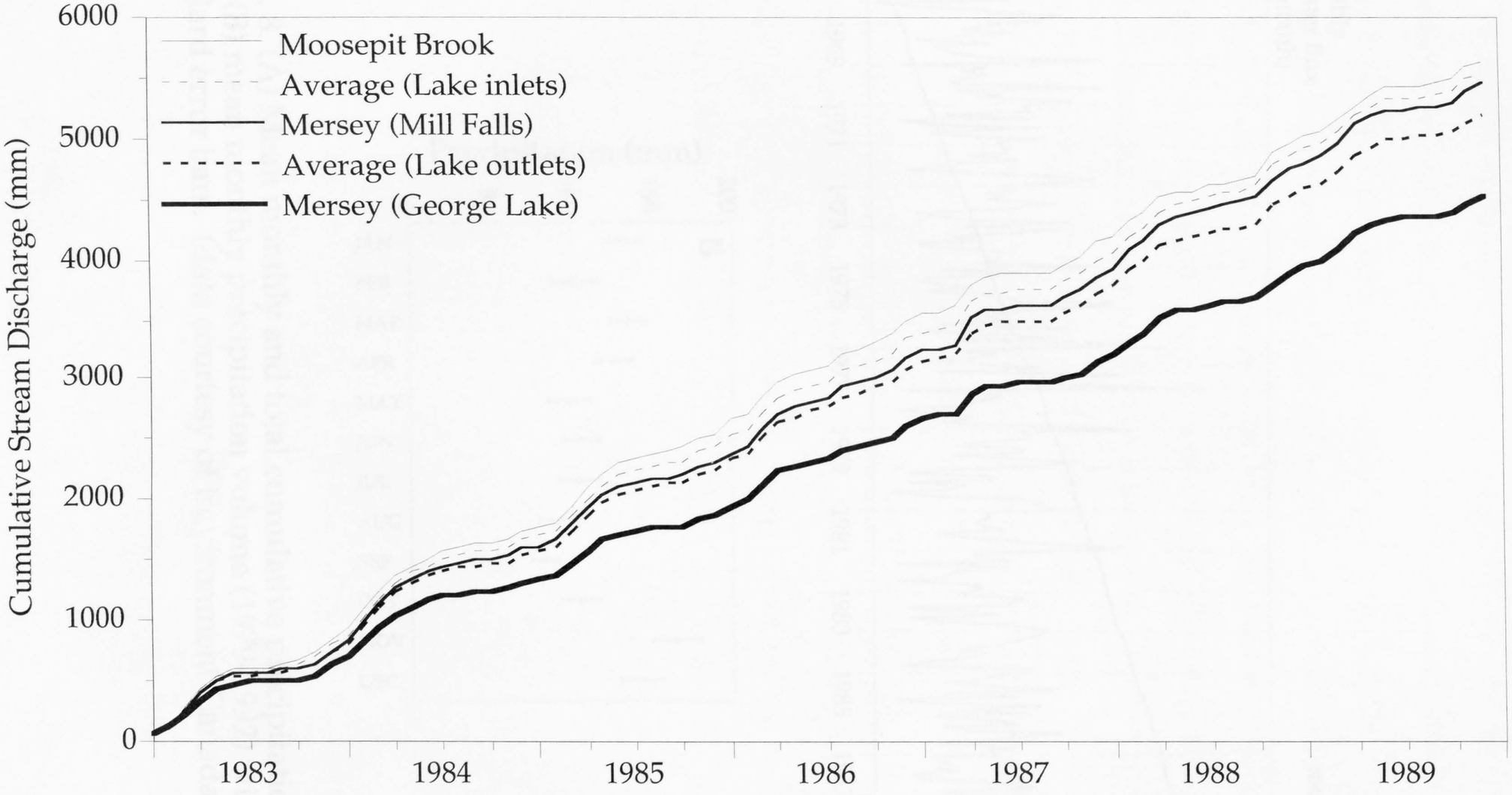
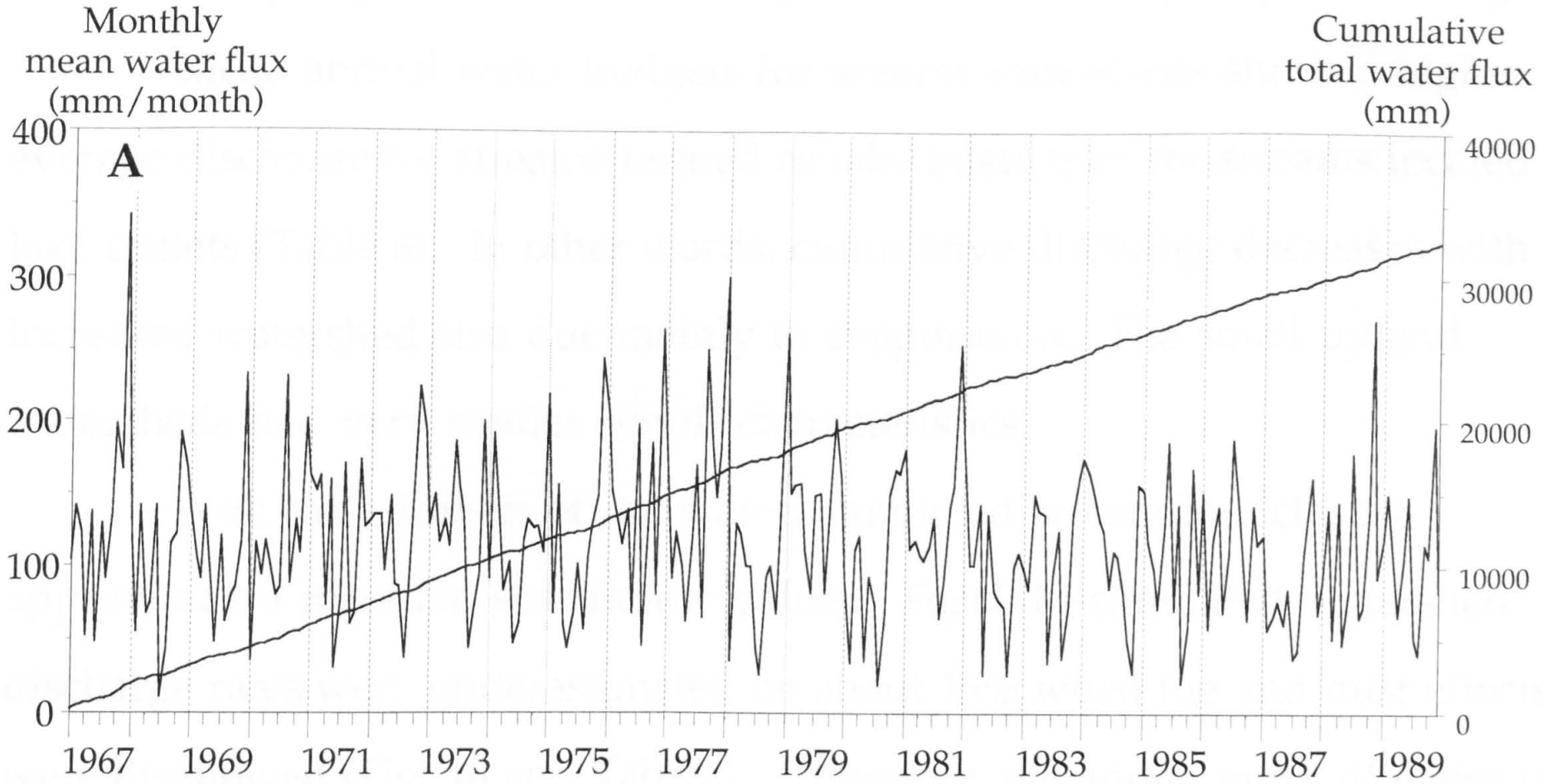


Fig. 7. Estimated averages for cumulative stream water discharge (mm) for lake inlets and lake outlets. Data courtesy of Environment Canada.



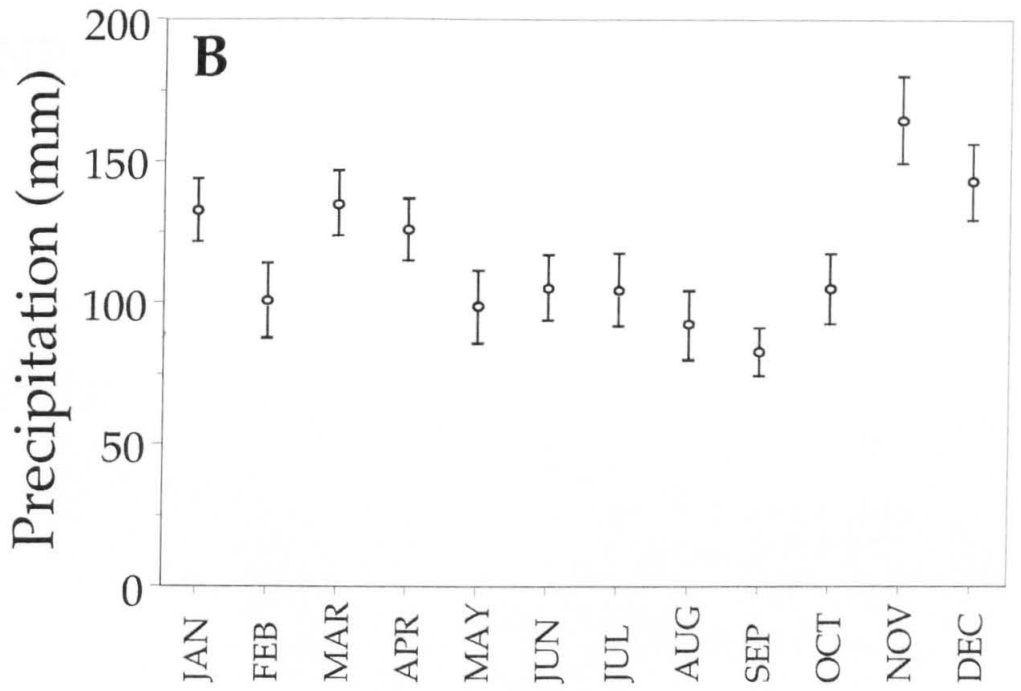


Fig. 8. (A) Mean monthly and total cumulative precipitation, and; (B) mean monthly precipitation volume (1979-1992) with standard error bars. (data courtesy of Environment Canada)

Streamflow

Estimated streamwater discharge ranged from 0 to 300 mm/month and tended to be lowest in late summer. Maximum values were during winter and spring in correlation with patterns found for precipitation (Fig. 9).

Mean annual water budgets for several watersheds showed higher average discharge for streams located as lake inlets than for streams located as lake outlets (Table 6). In other words, cumulative discharge decreases with increased watershed size due mainly to evaporation. The small upland watersheds had very similar runoff characteristics.

With the addition of fog water, simulated streamflow closely approximated recorded streamflow values. ForHyM-simulated watershed discharge rates were underestimated by about 15% when fog and mist effects were disallowed (Fig. 10 and Table 5). Therefore, the added input of water in the form of fog drip appears to be an important contribution to the overall water input at KNP.

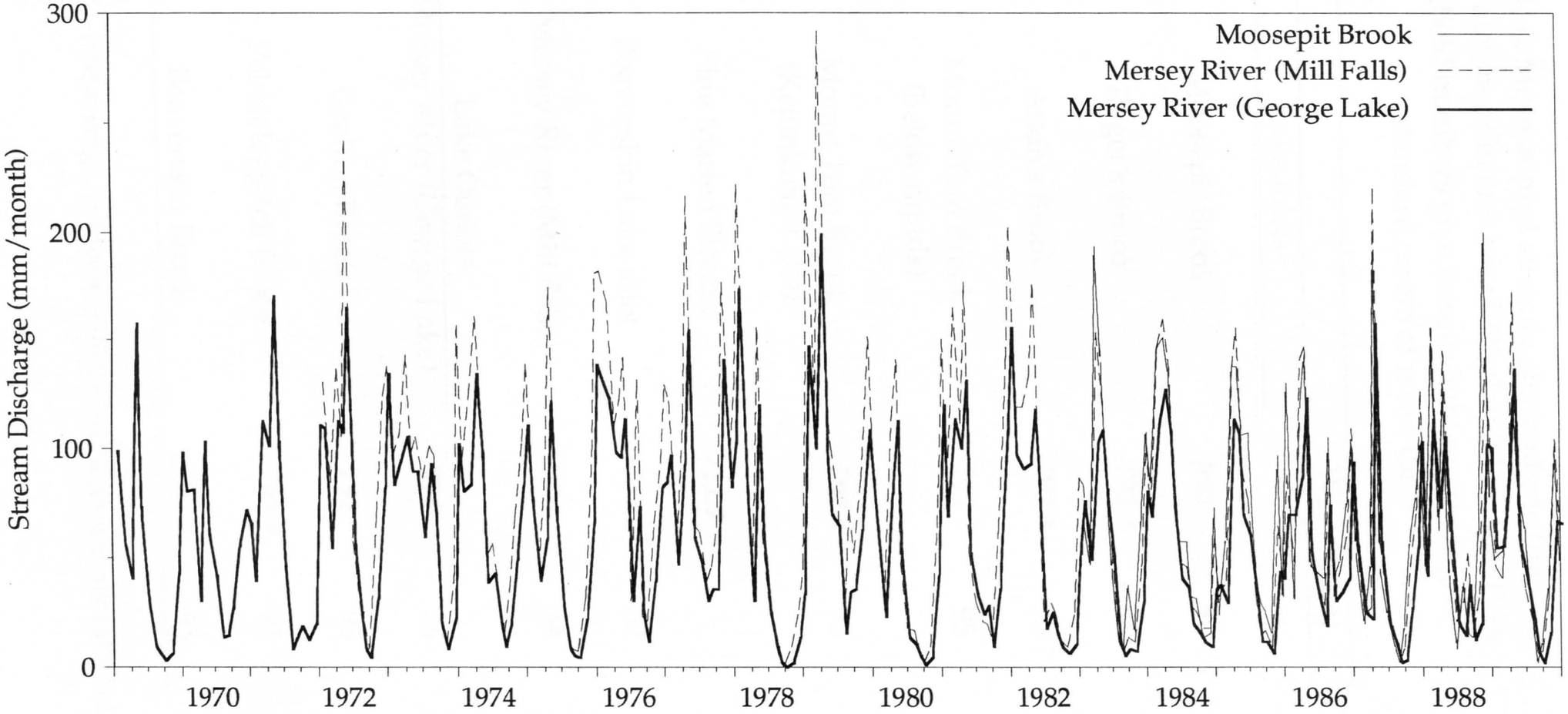


Fig. 9. Mean monthly stream discharge (mm/month) for monitored streams in and near Kejimkujik National Park.

Table 6. Mean annual streamwater budgets (mm) for watersheds in and near Kejimkujik National Park (Bold numbers give means; light numbers give standard errors of mean (SE))

	Water (mm)	
Lake Inlets		
Moosepit Brook	**805**	42
Roger's Brook	**792** *	95
Atkin's Brook	**792** *	95
Mount Tom Brook (below rapids)	**792** *	95
Mount Tom Brook (Kejimkujik Lake)	**792** *	95
Pine Marten Stream	**712.7**	-
Beaverskin Lake inlet	**743**	32
Mersey River (Mill Falls)	**779**	34
Lake Outlets		
Mersey River (George Lake)	**779**	26
Grafton Brook	**792** *	95
Pebbleloggitch Brook	**792** *	95
Beaverskin Brook	**792** *	95

* 1981-1988 average for Moosepit Brook and Mersey River (Mill Falls)

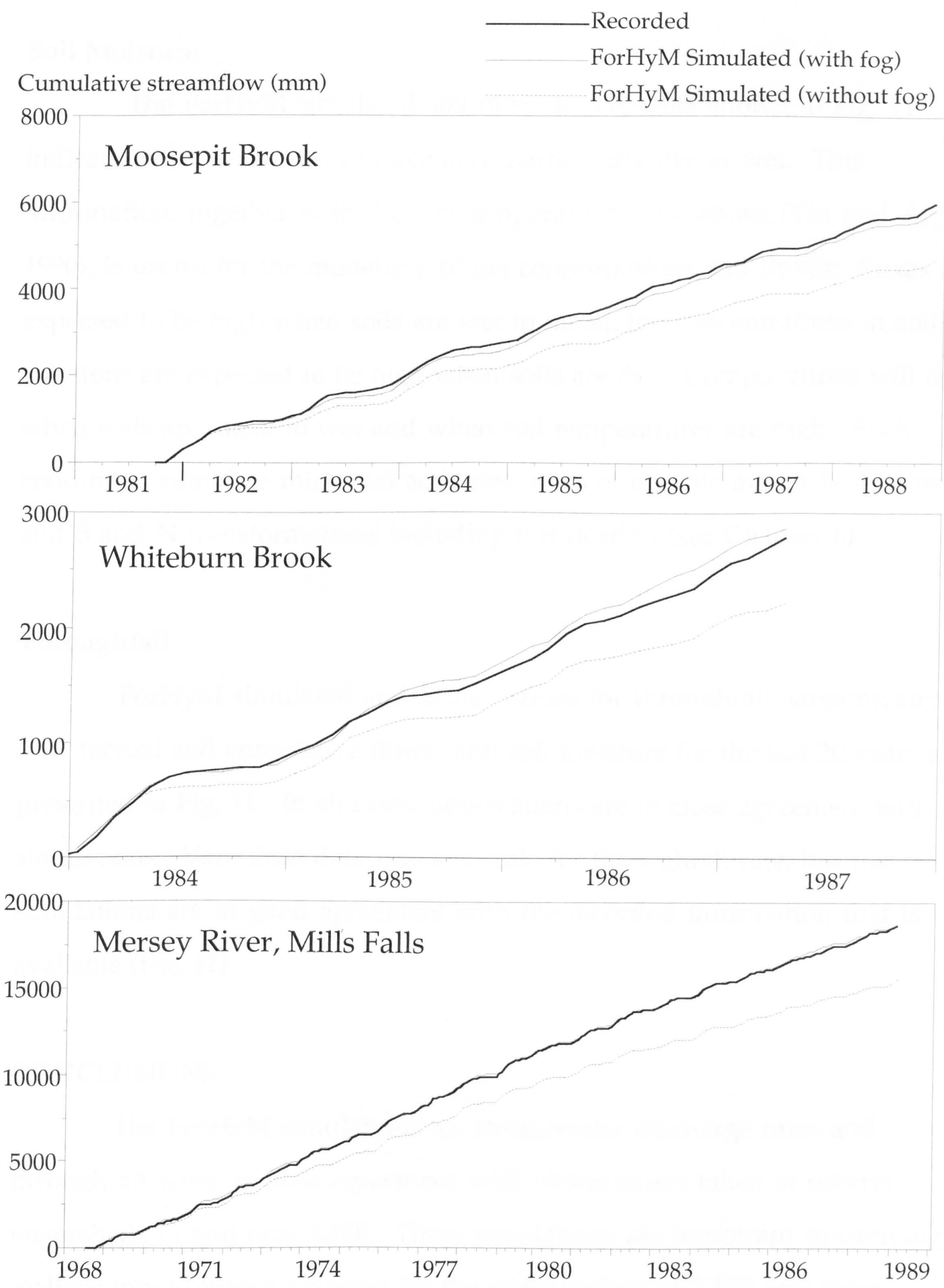


Fig. 10. Cumulative stream discharge simulations with or without fog and mist occurring in the watersheds for three streams in or near the Kejimkujik National Park in Nova Scotia, in relation to cumulative stream discharge records.

Soil Moisture

The ForHyM simulated soil moisture contents shown in Fig. 11 indicate which seasons may have been particularly dry or wet. This information, together with the soil temperature simulations (Yin and Arp 1990), is useful for the modelling of ion concentrations and fluxes: fluxes are expected to be high when soils are wet to moist; ion concentrations in soil solutions are expected to be high when soils are dry. Complications will occur when soils are moist to wet and when soil temperatures are high. Such conditions stimulate microbial activities, rates of organic matter breakdown, and S and N transformations including nitrification (see Chapter 6).

Throughfall

ForHyM simulated and actual values for throughfall, streamwater flow (actual and cumulative flows) and soil moisture for the last 20 years are presented in Fig. 11. In all cases, observations are in close agreement with simulations. Very little data was available for throughfall rate, but the simulations are in good agreement with the recorded information that is available (Fig. 11).

CONCLUSIONS

The ForHyM simulations for streamwater discharge rates and throughfall were in close agreement with observations taken at several watersheds in and near KNP. These simulations are important to deriving realistic input/output amounts for the water budget at KNP, and these amounts, in turn, are important to deriving realistic amounts of ion fluxes into, through, and out of the KNP watersheds (Chapter 5).

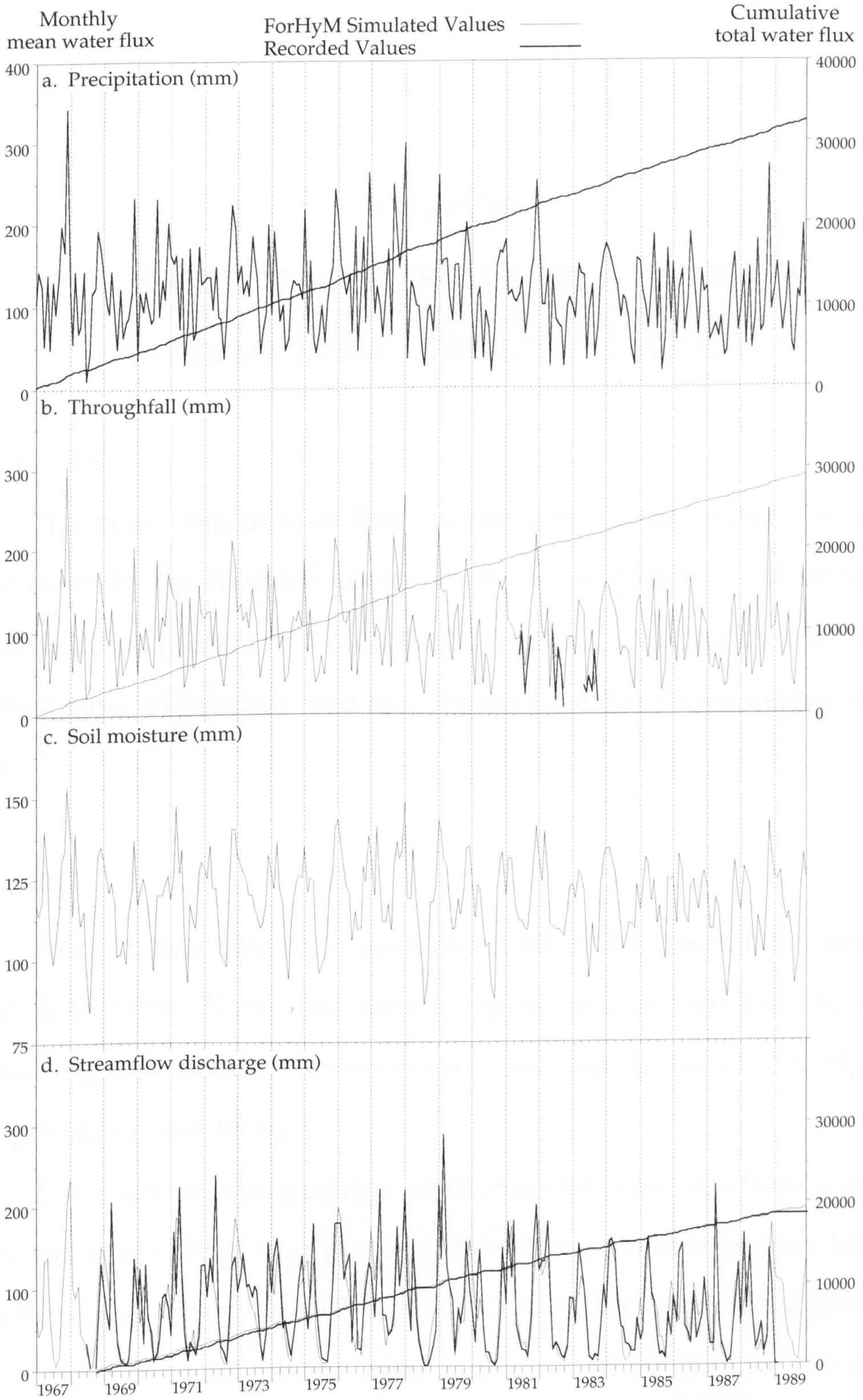


Fig. 11. Mean monthly and cumulative water fluxes (measured and simulated by ForHyM) for precipitation, throughfall, soil moisture and streamflow fluxes for Kejimkujik National Park. Throughfall data were collected at Beaverskin and Pebbleloggitch Lake watersheds (Percy 1989); streamwater data are those of Mersey River at MillFalls. Soil moisture simulations for a 50 cm deep soil.

CHAPTER 4

PRECIPITATION, THROUGHFALL, STEMFLOW AND STREAMWATER IN KEJIMKUJIK NATIONAL PARK: CHEMICAL COMPOSITION

OBJECTIVES

The main objectives of this chapter are: (*i*) to outline the methods used to describe the chemical composition of precipitation and streamwater at KNP, and; (*ii*) to present and discuss the results as affected by season, watershed type, vegetation type and stream type (lake inlet versus lake outlet).

METHODS

Precipitation data have been recorded at the CAPMoN station located in KNP since 1979. These data were compiled and summarized in terms of volume-weighted monthly ion concentrations (mg/L) for H, Ca, Mg, K, Na, Cl, SO_4, NH_4-N, and NO_3-N.

The chemical composition of throughfall and stemflow was determined over a three year period (1981-1983) at Pebbleloggitch Lake and Beaverskin Lake watersheds (Percy 1989). Monthly volume-weighted ion concentrations were calculated using precipitation volume for the same sites as a weighting basis. A summary for mean annual stemflow and throughfall was prepared for S, Fe, Mn, H, Ca, Mg, K, Na, Cl, Al, SO_4, NH_4-N and NO_3-N.

Streamwater chemistry data were compiled as volume-weighted

monthly concentrations (H, Ca, Mg, K, Na, Cl, Fe, Mn, Al, SO_4, and NO_3-N).

RESULTS AND DISCUSSION

Precipitation

Average annual concentrations and annual precipitation totals are presented in Table 7. Average monthly volume-weighted ion concentrations, pH, and monthly precipitation volumes are presented in Fig. 12. As shown, pH of precipitation was low overall, averaging about 4.6. Fluctuations in pH paralleled the seasonal trends seen for precipitation volume (see Chapter 3): minimum values occurred in summer, and peaks occurred in winter.

Large deposition events ("episodes") showed that a high percentage of the annual wet deposition was deposited by only a small percentage of precipitation days during each year. Meteorological situations that produced most of these episodes were related to southwesterly or westerly wind flows, followed by the passage of precipitation-bearing weather systems generally arriving from the west (Beattie and Whelpdale 1989). Heavily industrialized regions in the United States and Canada are likely responsible for the highly acidic precipitation at KNP, as shown by air mass trajectory calculations (Beattie and Keddy 1993).

Atmospheric NO_3-N, NH_4-N, and SO_4 deposition concentrations were related to H deposition, and peaked during spring and early summer. Minimum values occurred during winter. Similar results were found in a KNP study spanning the years 1978 to 1987 (Underwood *et al.* 1989). Seasonal fluctuations for SO_4 were greater than for NO_3. Spring and summer NO_3 concentrations were higher than fall and winter concentrations.

Table 7. Mean annual precipitation chemistry (mg/L) measured at the CAPMoN station

Year	H	Ca	Mg	K	Na	Cl	SO4	NH4-N	NO3-N	Volume (mm)
1979	0.03	0.15	0.08	0.07	0.64	1.10	1.96	0.12	0.23	1051
1980	0.03	0.19	0.10	0.07	0.79	1.47	1.89	0.10	0.23	1191
1981	0.03	0.20	0.12	0.09	0.94	1.61	1.86	0.10	0.24	1625
1982	0.03	0.21	0.13	0.11	1.11	1.77	1.88	0.09	0.25	1260
1983	0.03	0.21	0.13	0.12	1.10	1.78	1.67	0.09	0.23	1345
1984	0.03	0.24	0.13	0.12	1.07	1.77	1.87	0.11	0.26	1315
1985	0.04	0.26	0.12	0.12	1.02	1.67	1.93	0.12	0.26	1299
1986	0.04	0.21	0.10	0.12	0.94	1.48	1.89	0.10	0.25	1454
1987	0.04	0.22	0.08	0.11	0.78	1.12	2.01	0.10	0.24	1238
1988	0.05	0.16	0.06	0.11	0.60	0.69	2.09	0.12	0.25	1428
1989	0.05	0.17	0.05	0.09	0.53	0.64	2.16	0.13	0.24	1305
1990	0.05	0.18	0.05	0.06	0.37	0.50	2.14	0.13	0.24	1608
1991	0.05	0.19	0.06	0.07	0.42	0.57	2.11	0.12	0.25	1437

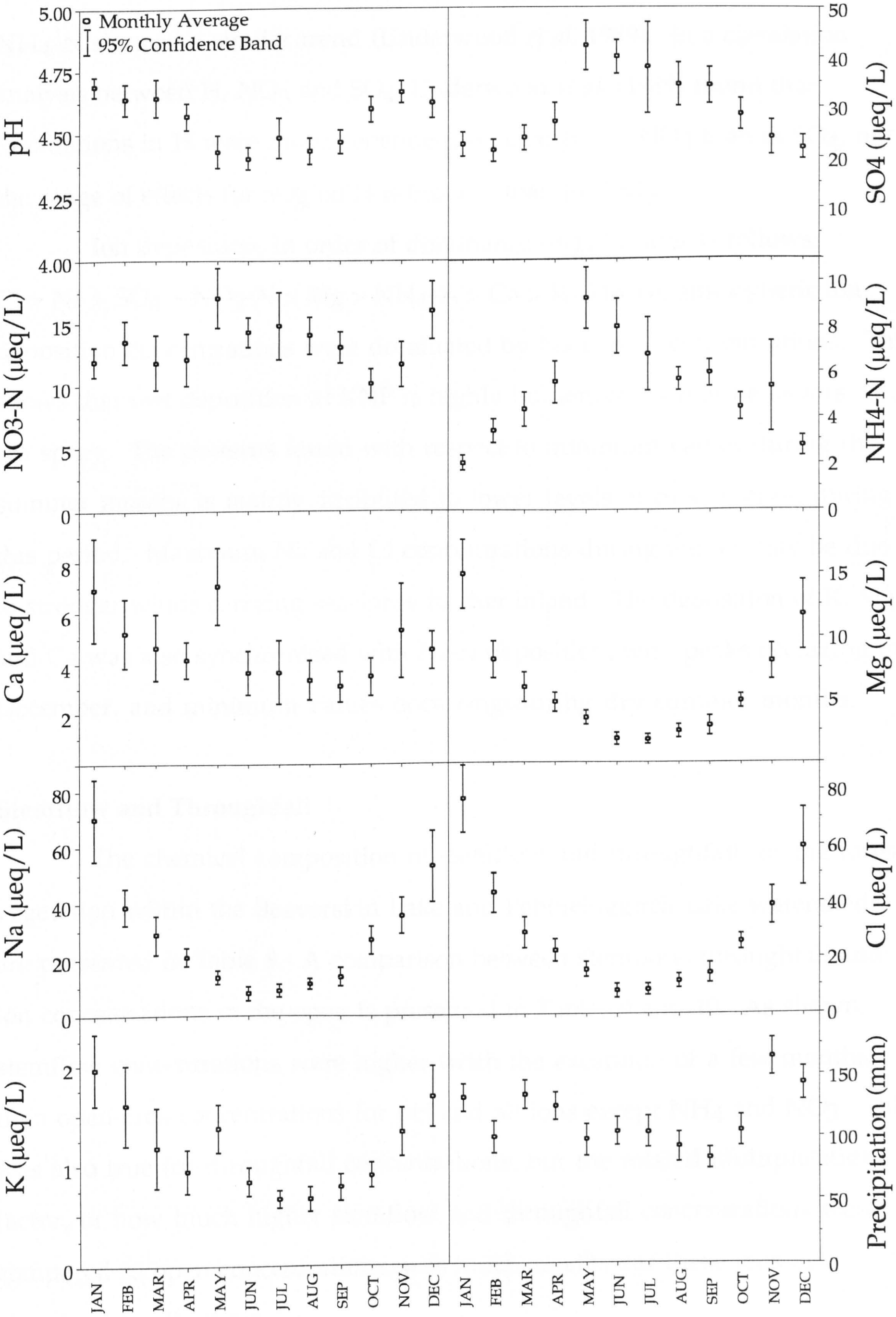


Fig. 12. Mean monthly precipitation ion concentrations (µeq/L) and precipitation totals (mm) for Kejimkujik National Park measured at the CAPMoN station.

NH_4-N showed a similar trend (Underwood *et al.* 1989). In a correlation analysis between H, NO_3 and SO_4, Underwood *et al.* (1989) found that fluctuations in H were more dependent on changes in NO_3 than in SO_4, but the range of effects for SO_4 on H is broader than for NO_3.

Ion deposition, in order of dominance (mg/L), was as follows: Cl > Na > SO_4 > NO_3-N > Mg > NH_4-N > Ca > K. Hence, atmospheric ion deposition concentrations were dominated by Na and Cl concentrations. This shows that wet deposition at KNP is highly influenced by marine factors, i.e., sea spray. The patterns found with respect to minimum values during the summer months is mainly attributed to lower levels of precipitation during this period. Maximum Na and Cl concentrations during winter may be due to stronger winds carrying sea spray further inland. The deposition of K, Mg, and Ca was also synchronized with NaCl deposition, with peaks occurring in December, and minimum values occurring during dry summer months.

Stemflow and Throughfall

The chemical composition of stemflow and throughfall for the forest vegetation within the Beaverskin Lake and Pebbleloggitch Lake watersheds are presented in Table 8. A comparison between stemflow, throughfall and ion concentrations in the open is presented in Tables 9 and 10. As shown, stemflow concentrations were higher (with the exception of a few months) than open-area concentrations for pH and all ions except NH_4 and NO_3. This was also true for throughfall concentrations, but the related multiplication factor, or how much higher stemflow and throughfall concentrations were compared to open concentrations, was much smaller for these ions as compared to all others.

Table 8. Mean annual stemflow and throughfall chemical composition (mg/L) measured under the forest vegetation at Beaverskin and Pebbleloggitch Lake watersheds

	YEAR	S	Mn	Fe	Mg	Al	Ca	Na	K	N	NH4	NO3	Cl	SO4	pH
Stemflow	1981	-	0.06	0.01	0.32	-	0.68	1.43	3.27	0.45	0.05	0.10	-	5.16	4.67
	1982	1.68	0.22	0.02	0.99	0.05	1.70	2.89	5.80	0.67	0.01	0.01	1.28	1.94	4.46
	1983	1.30	0.05	0.01	0.36	0.03	0.96	1.84	4.89	1.89	0.03	0.04	1.57	3.88	4.78
Throughfall	1981	-	0.05	0.01	0.13		0.37	0.67	0.73	0.25	0.04	0.03		1.80	4.64
	1982	1.05	0.11	0.01	0.35	0.09	0.96	1.23	2.19	0.51	0.04	0.21	0.70	0.90	4.59
	1983	0.85	0.05	0.01	0.29	0.02	0.57	11.21	2.20	1.44	0.06	0.08	1.33	2.54	4.64

Table 9. Stemflow concentrations (mg/L) showing monthly averages and multiplification factor (+ve or -ve) for precipitation concentrations (measured in the open)

	pH		S		P		Pb		Mn		Fe		Mg		Al		Ca	
DATE	Average	X Open†	Average	X Open†	Average	X Open†	Average	X Open†	Average	X Open†	Average	X Open†	Average	X Open†	Average	X Open†	Average	X Open†
Jun-81	4.7	+1.05					0.25	+10.08	0.04	+11.00	0.04	+2.24	0.23	+10.27			0.46	+2.85
Jul-81	4.8	+1.02					0.34	+7.04	0.03	+2.31			0.25	+13.94			0.60	+2.24
Aug-81	4.6	+1.04											0.49	+54.89			1.00	+17.49
Sep-81	4.7	+1.05																
Oct-81	4.5	+1.02																
May-82	3.7	-0.95					1.10	+1.65	0.43	-0.15			2.50	+12.87			2.69	+1.84
Jun-82	4.6	-0.99	1.04	+1.88	0.06	+1.90	0.37	+92.75					0.37	+6.54	0.03	+1.88	1.05	+2.79
Jul-82	4.5	-0.90	1.87	+3.20	0.28	+2.84	0.67	+337.00	0.25	+83.00			0.93	+9.27	0.08	+4.26	2.09	+3.61
Aug-82	4.9	+1.05	0.84	+1.84	0.22	+2.60	0.24	+11.80	0.04	+6.67			0.16	+1.99	0.04	-0.14	0.62	+2.22
Sep-82	4.7	-0.99	1.77	+2.30	0.33	+3.09	0.48	+53.00			0.04	+13.00	0.45	+14.45	0.06	+6.33	1.20	+5.50
Oct-82	4.3	+1.15	4.57	+2.36	0.07	-0.33	0.78	+39.00	0.42	+52.63	0.03	-0.47	1.53	+10.34	0.07	+2.03	2.56	+4.55
May-83	5.0	+1.09	0.93	+1.30	0.04	-0.42	0.85	+9.96	0.03	+29.00	0.00	+4.00	0.14	+1.97	0.02	+0.95	0.39	+1.50
Jun-83	4.9	+1.14	1.50	+1.37	0.05	+1.74	0.71	+14.41	0.04	+10.75	0.01	+1.17	0.23	+6.08	0.03	+1.25	0.68	+1.98
Jul-83	4.4	+1.01	1.45	+3.51	0.10	+2.16			0.07	+35.00	0.01	+1.40	0.44	+14.80	0.03	+1.04	1.34	+16.94
Aug-83	4.9	+1.04	1.04	+1.72	0.19	+1.91	0.36	+51.14	0.04	+3.00			0.26	+37.71	0.01	-0.36	0.71	+26.44
Sep-83	4.8	-0.99	1.07	+2.13	0.13	+2.44	0.39	+27.79	0.03	+6.80	0.01	+1.40	0.28	+5.46	0.03	+2.55	0.71	+4.57
Oct-83	4.6	-0.93	1.82	+4.76	0.19	+3.38	1.31	+3.98	0.10	+20.40			0.79	+4.91	0.09	+7.42	1.91	+11.25

	Cu		Na		K		N		NH4		NO3		Cl		SO4	
DATE	Average	X Open†	Average	X Open†	Average	X Open†	Average	X Open†	Average	X Open†	Average	X Open†	Average	X Open†	Average	X Open†
Jun-81	0.06	+1.36	1.38	+2.77	2.16	+29.19	0.20	+3.38							3.55	+5.51
Jul-81			1.59	+1.98	3.00	+46.88	0.39	+1.37	0.06	-0.83	0.19	+8.59			5.23	+2.90
Aug-81			1.32	+10.54	4.64	+193.33	0.75	+17.00							6.71	+43.88
Sep-81																
Oct-81																
May-82			6.32	+4.62	6.46	+24.12	0.47	+0.99					2.37	+4.58	11.66	+4.21
Jun-82	0.03	+1.21	2.07	+6.57	3.37	+5.50	0.48	+2.41	0.03	-0.66	0.02	-0.09	0.55	+2.65		
Jul-82	0.03	+1.00	2.94	+3.79	7.02	+23.49	1.25	+1.71	0.02	-0.15	0.01	-0.10	1.19	+3.09		
Aug-82	0.03	-0.85	1.32	+1.85	3.37	+29.30	0.59	+1.42	0.00	-0.06	0.01	-0.07	0.31	+2.61		
Sep-82	0.02	+2.18	1.86	+2.40	6.35	+22.83	0.77	+1.40	0.04	-0.22	0.03	-0.10	0.62	+3.26		
Oct-82	0.06	+1.81	2.85	+2.93	8.20	+23.97	0.45	-0.45	0.00	-0.00	0.02	-0.05	2.67	+1.50		
May-83	0.03	+1.27	1.50	-0.19	2.12	+14.49	1.23	+1.37	0.03	-0.16	0.04	-0.18	0.52	+3.02	2.72	+1.28
Jun-83	0.01	+1.14	3.17	-0.13	3.01	+24.44	1.14	-0.99	0.01	-0.03	0.06	-0.16	0.85	+1.62	4.47	+1.35
Jul-83	0.02	+1.00	1.97	-0.30	6.13	+49.00	3.03	+1.69	0.04	+1.22	0.06	-0.28	1.00	+3.00	4.37	+3.59
Aug-83	0.06	+1.67	1.10	-0.37	4.29	+72.75	2.42	-0.88	0.06	-0.62	0.02	-0.10	0.88	+7.48	3.11	+1.77
Sep-83	0.02	+1.78	1.06	-0.12	4.31	+86.28	2.67	+2.38	0.02	-0.47	0.02	-0.11	1.63	+1.60	3.18	+2.10
Oct-83	0.05	-0.80	2.26	-0.16	9.50	+58.99	0.83	+14.22			0.03	-0.32	4.55	+1.97	5.45	+4.64

† multiplification factor between stemflow concentrations and precipitation (open) concentrations

Table 10. Throughfall concentrations (mg/L) showing monthly averages and multiplification factor (+ve or -ve) for precipitation concentrations (measured in the open)

	pH		S		P		Pb		Mn		Fe		Mg		Al		Ca	
DATE	Average	X Open†	Average	X Open†	Average	X Open†	Average	X Open†	Average	X Open†	Average	X Open†	Average	X Open†	Average	X Open†	Average	X Open†
Jun-81							0.01	-0.52	0.04	+9.25	0.02	+1.18	0.15	+6.64			0.35	+2.21
Jul-81	4.9	+1.03					0.03	-0.58	0.03	+2.46			0.14	+7.56			0.41	+1.54
Aug-81	4.4	+1.01											0.11	+12.11			0.34	+5.96
Sep-81	4.7	+1.06																
Oct-81	4.5	+1.02																
May-82	4.0	+1.01					0.58	-0.87	0.10	-0.03			0.57	+2.91			1.46	+1.00
Jun-82	4.8	+1.03	0.81	+1.46	0.05	+1.68	0.03	+8.25					0.21	+3.75	0.04	+2.53	0.70	+1.86
Jul-82	4.8	-0.94	0.82	+1.41	0.09	+0.89	0.01	+7.00	0.07	+24.00			0.27	+2.65	0.04	+2.32	0.89	+1.54
Aug-82	5.0	+1.06	0.60	+1.31	0.08	+1.00	0.02	+1.05	0.06	+10.50			0.13	+1.63	0.18	-0.69	0.39	+1.40
Sep-82	4.7	+1.00	1.03	+1.34	0.06	+0.57	0.02	+2.56			0.02	+6.33	0.21	+6.65	0.02	+1.89	0.58	+2.65
Oct-82	4.3	+1.16	3.05	+1.58	0.27	+1.33	0.02	+1.05	0.23	+28.13	0.02	-0.27	0.70	+4.72	0.27	+8.44	1.73	+3.07
May-83	4.7	+1.02	0.74	+1.04	0.03	+0.33	0.11	+1.32	0.01	+8.00	0.00	+3.00	0.11	+1.54	0.01	-0.45	0.27	+1.06
Jun-83	4.5	+1.04	1.18	+1.08	0.08	+2.42	0.07	+1.33	0.02	+4.75	0.00	+0.50	0.17	+4.47	0.02	+0.90	0.41	+1.20
Jul-83	4.4	+1.01	0.80	+1.93	0.09	+1.95			0.04	+18.50	0.01	+0.60	0.26	+8.70	0.04	+1.44	0.50	+6.28
Aug-83	4.8	+1.02	0.79	+1.30	0.12	+1.25			0.02	+1.43			0.15	+20.71	0.01	-0.43	0.29	+10.63
Sep-83	4.8	-0.99	0.66	+1.32	0.04	+0.77	0.01	-0.50	0.02	+4.20	0.00	+0.20	0.20	+3.83	0.01	+1.18	0.38	+2.45
Oct-83	4.6	-0.93	0.93	+2.42	0.66	+11.95	0.20	-0.60	0.18	+35.20			0.84	+5.24	0.05	+4.33	1.56	+9.15

	Cu		Na		K		N		NH4		NO3		Cl		SO4	
DATE	Average	X Open†	Average	X Open†	Average	X Open†	Average	X Open†	Average	X Open†	Average	X Open†	Average	X Open†	Average	X Open†
Jun-81	0.07	+1.48	0.83	+1.67	0.91	+12.27	0.17	+2.90							1.87	+2.91
Jul-81			0.91	+1.13	0.74	+11.58	0.33	+1.17	0.05	-0.63	0.06	+2.68			2.39	+1.33
Aug-81			0.28	+2.22	0.54	+22.38	0.25	+5.73							1.13	+7.37
Sep-81																
Oct-81																
May-82			2.30	+1.68	2.53	+9.42	0.35	-0.75	0.03	-0.11	0.33	-0.42	0.94	+1.82	5.42	+1.96
Jun-82	0.03	+1.17	0.73	+2.33	1.91	+3.11	0.48	+2.42	0.02	-0.51	0.03	-0.18	0.30	+1.44		
Jul-82	0.03	+1.11	0.91	+1.18	1.69	+5.67	1.02	+1.40	0.04	-0.38	0.04	-0.40	0.63	+1.64		
Aug-82	0.04	+1.00	0.48	-0.67	0.81	+7.04	0.54	+1.32	0.06	+0.98	0.09	-0.48	0.15	+1.28		
Sep-82	0.02	+2.09	0.84	+1.09	1.84	+6.62	0.39	-0.72	0.04	-0.26	0.60	+2.28	0.33	+1.74		
Oct-82	0.04	+1.22	2.11	+2.17	4.38	+12.81	0.25	-0.25	0.05	-0.05	0.19	-0.48	1.86	+1.05		
May-83	0.03	+1.08	7.77	-0.97	0.78	+5.34	1.31	+1.46	0.03	-0.15	0.10	-0.45	0.24	+1.39	2.22	+1.05
Jun-83	0.03	+3.86	22.11	-0.89	1.22	+9.92	1.62	+1.40	0.02	-0.16	0.18	-0.48	0.57	+1.08	3.54	+1.07
Jul-83	0.01	-0.57	8.00	+1.22	2.16	+17.25	2.38	+1.33	0.11	+2.97	0.09	-0.45	0.60	+1.78	2.39	+1.96
Aug-83	0.03	+0.97	3.68	+1.25	1.36	+23.10	2.23	-0.81	0.13	+1.42	0.05	-0.36	0.34	+2.87	2.33	+1.33
Sep-83	0.00	-0.44	6.00	-0.67	1.45	+28.98	0.99	-0.88	0.07	+1.86	0.06	-0.48	1.16	+1.13	1.98	+1.31
Oct-83	0.07	+1.18	19.68	+1.40	6.24	+38.74	0.09	+1.59			0.01	-0.06	5.07	+2.19	2.79	+2.38

† multiplification factor between throughfall concentrations and precipitation (open) concentrations

A notable exception was found for stemflow K during the months in 1983: throughfall and stemflow tended to increase the K concentrations, and a multiplication factor of up to 337 was found between stemflow and throughfall versus open concentrations. Usually this factor ranged from 1 to 10. In general, throughfall tends to enrich K concentrations (Foster 1979), and Na, Mg, Ca, and SO_4 concentrations as well (Hart *et al.* date unknown).

The forest canopy, as shown for the Pebbleloggitch and Beaverskin Lake watersheds in KNP, influenced the ion concentrations of atmospheric deposition in several ways. Specifically, chemicals deposited in tree canopies may just stay there, and/or enter into ion exchange reactions on foliage and bark surfaces (Mahendrappa 1989). As a result, some nutrients are removed from foliage by ion exchange, and some nutrients are simply washed from the canopies (Lovett *et al.* 1985). Hence, ion concentrations in stemflow are generally much higher than in either rain water or throughfall. This was also a conclusion drawn by Mahendrappa (1974). NH_4-N and NO_3 concentrations, however, were not enriched in stemflow and throughfall. Consequently, incoming NO_3-N and NH_4-N must have been absorbed in various plant surfaces within the tree canopies (see also Mahendrappa 1989).

Streamwater

Table 11 outlines the ion concentration levels and seasonal patterns found for streamwater. Figures 13 through 18 show the extent to which stream chemistry is dominated by annual cycles.

Table 11. Results found for streamwater ion concentrations in and near Kejimkujik National Park

CATEGORY *		CONCENTRATION RANGES	SEASONAL PATTERNS (TIMING)				COMMENTS	
			Minimum Concentrations		Maximum Concentrations			
			Lake Inlets	Lake Outlets	Lake Inlets	Lake Outlets	Lake Inlets	Lake Outlets
1	**Na**	1-6 mg/L	spring	spring	fall	winter	peaks not pronounced average around 3 mg/L	
	Cl	2-9 mg/L	spring	spring-summer	summer-late fall	winter	average 4-5 mg/L peaks last through summer	
	Mg	.25-1.75 mg/L	spring	spring	fall	winter	seasonality very distinct peaks last longer than for Ca more variable	
	Ca	.25-2.5 mg/L	spring	spring	fall	fall	more variable seasonality very distinct	
2	**K**	.1-2.0 mg/L	summer, winter	summer, winter	spring, fall	spring, fall	two peaks, not obvious average .25 mg/L	
3	**Organic Anions**	.05-8.5 mg/L	spring	spring	summer-fall	fall-winter	more varied seasonality distinct average 3-4 mg/L	not much data average 1 mg/L
	Al	.05-.5 mg/L	spring	spring	late summer-fall	fall-winter	distinct seasonality	not much data
	Fe	0.1-4 mg/L	winter-spring	winter-spring	summer-fall	summer-fall	average 1 mg/L Roger's Brook very distinct seasonal trend	average 0.3 mg/L
	Mn	.01-.45 mg/L	winter-spring	winter-spring	late summer-fall	late summer-fall	Roger's Brook very distinct seasonal trend	not much data
4	**NO3-N †**	.01-.15 mg/L	summer	summer	fall	winter		more variable
	NH4-N	no data	no data		no data			
	SO4	<1-9 mg/L	summer	not distinct	winter	not distinct	seasonality very distinct pattern opposes pH	average 2 mg/L
	pH	3.75-6.5	fall-winter	spring	summer	fall	average 4.5-5	more variable
	H2O	0-300 mm/month	late summer	late summer	winter-spring	winter-spring		

* Categories defined in Chapter 4

† NO3-N estimates taken from NO2 and NO3 measurements

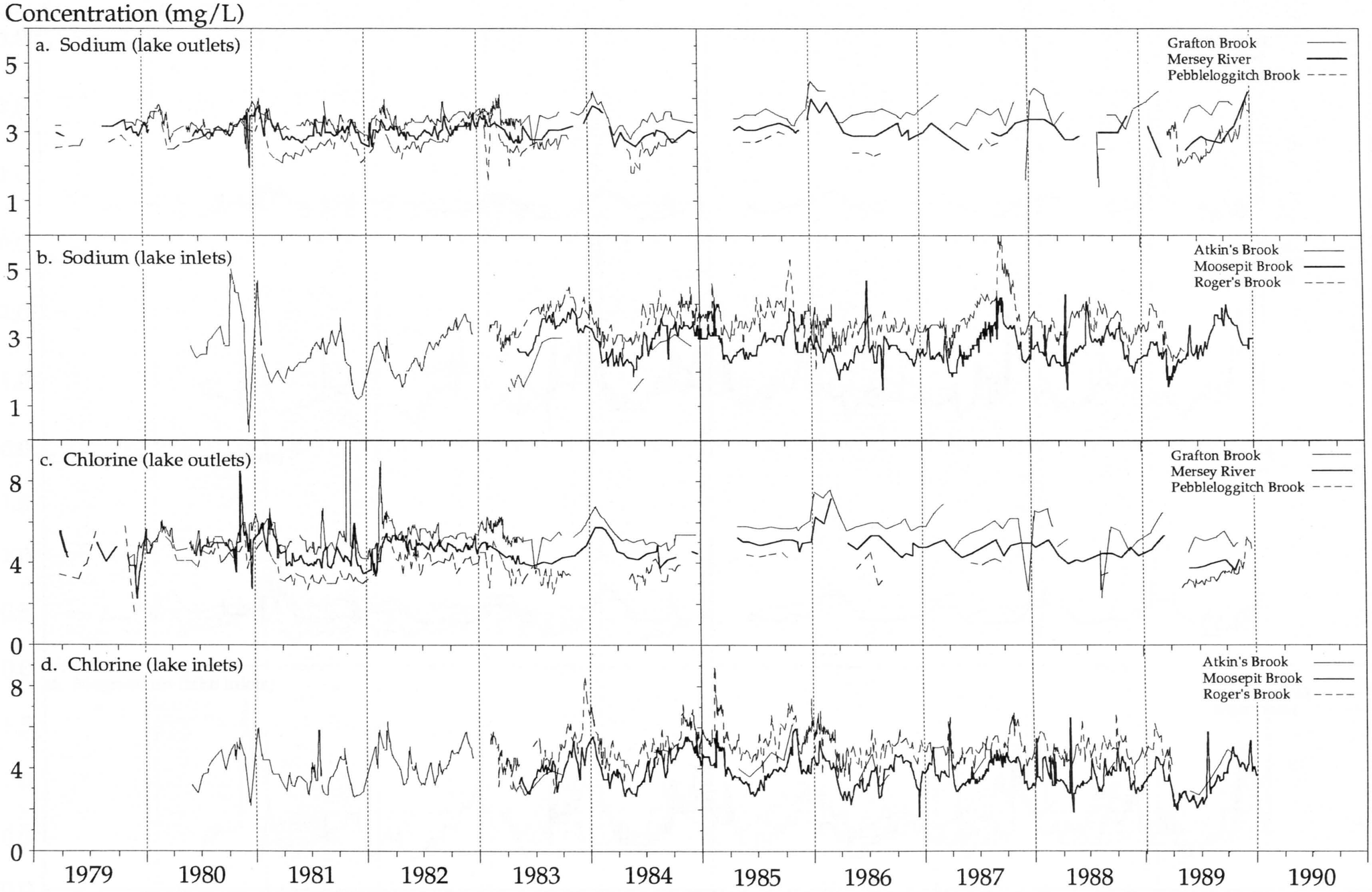


Fig. 13. Stream water concentrations (original data) for: a. sodium in lake outlets; b. sodium in lake inlets; c. chlorine in lake outlets; d. chlorine in lake inlets.

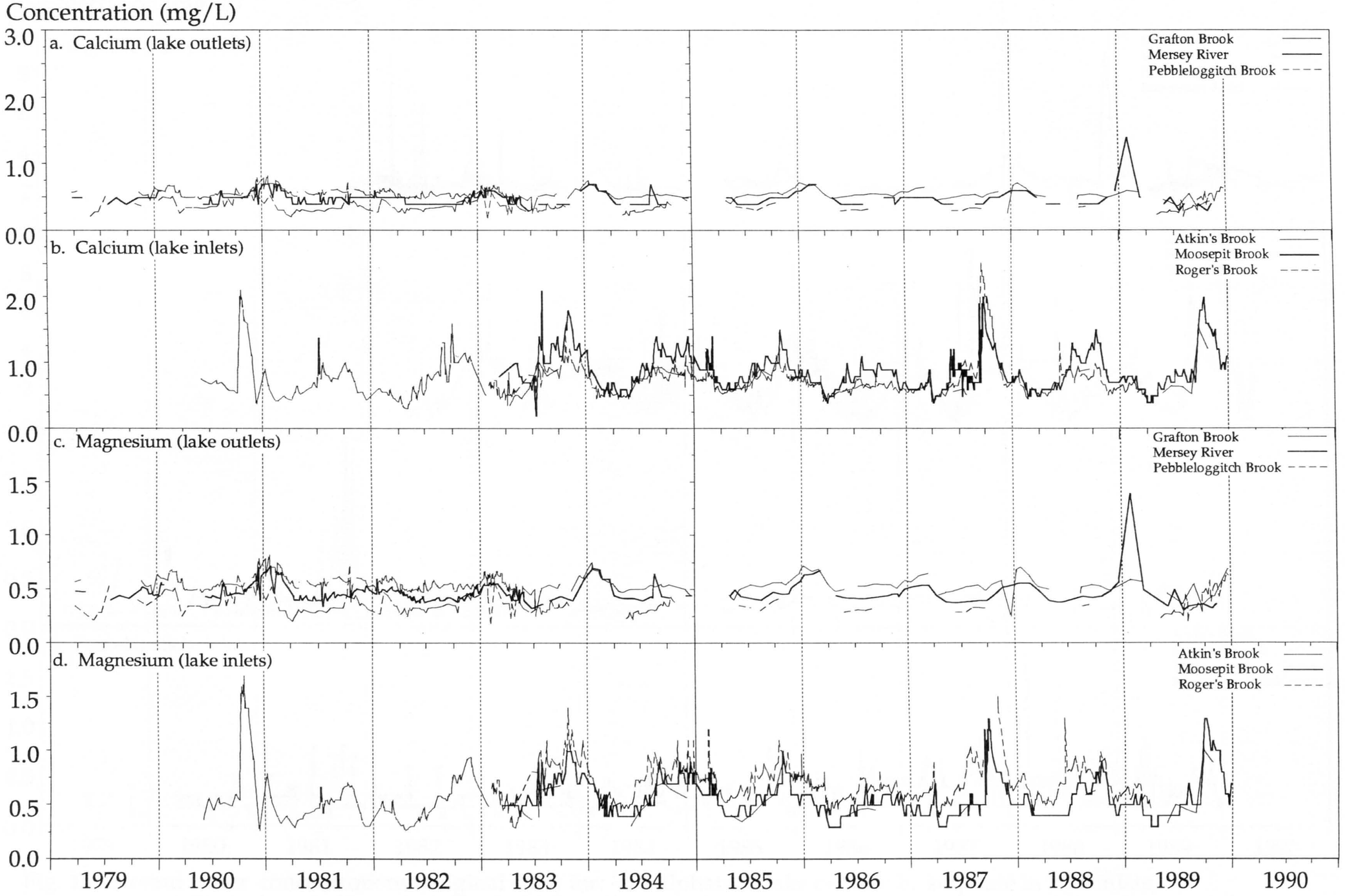


Fig. 14. Stream water concentrations (original data) for: **a.** calcium in lake outlets; **b.** calcium in lake inlets; **c.** magnesium in lake outlets; **d.** magnesium in lake inlets.

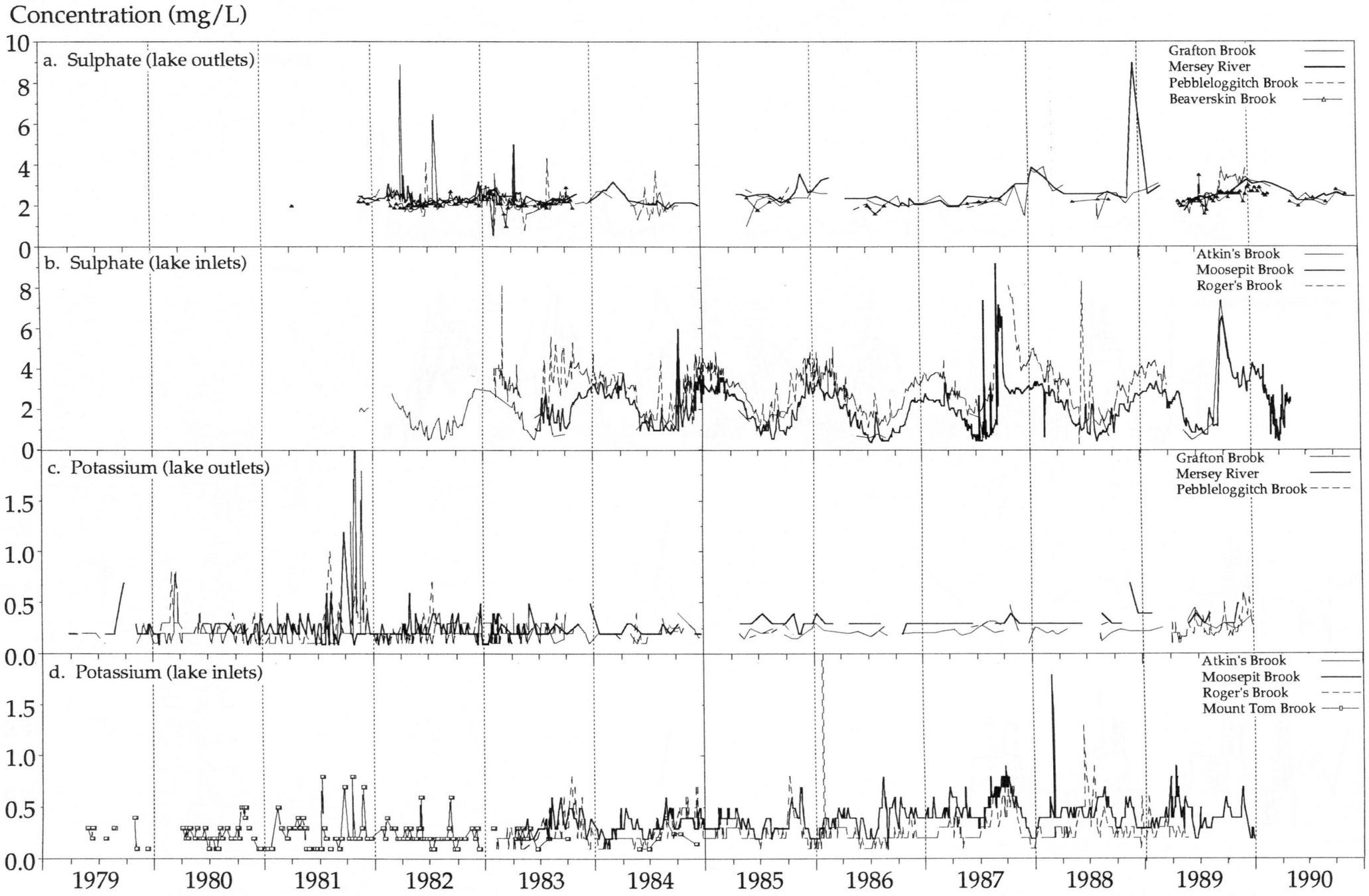


Fig. 15. Stream water concentrations (original data) for: **a.** sulphate in lake outlets; **b.** sulphate in lake inlets; **c.** potassium in lake outlets; **d.** potassium in lake inlets.

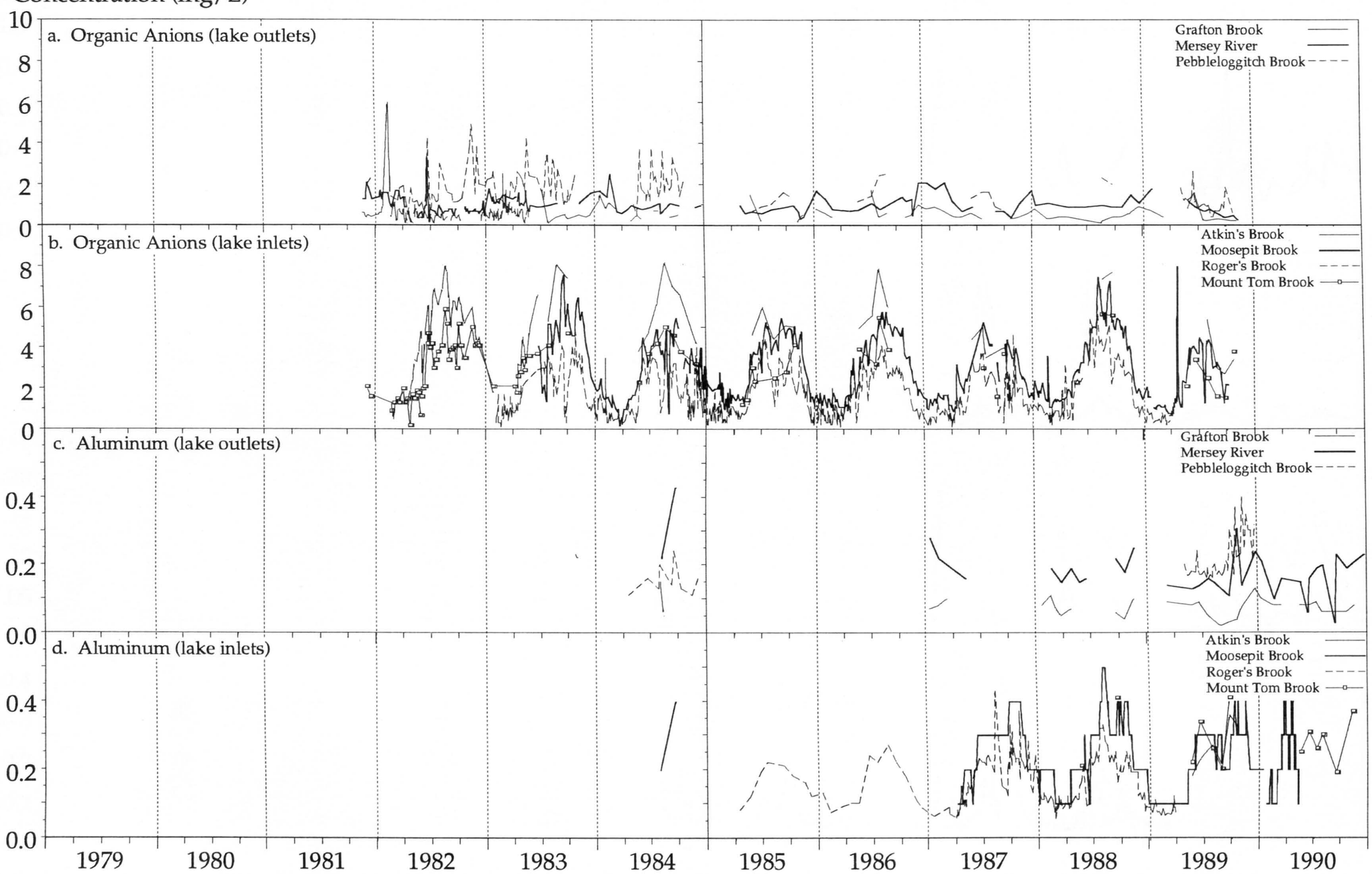


Fig. 16. Stream water concentrations (original data) for: a. organic anions in lake outlets; b. organic anions in lake inlets; c. aluminum in lake outlets; d. aluminum in lake inlets.

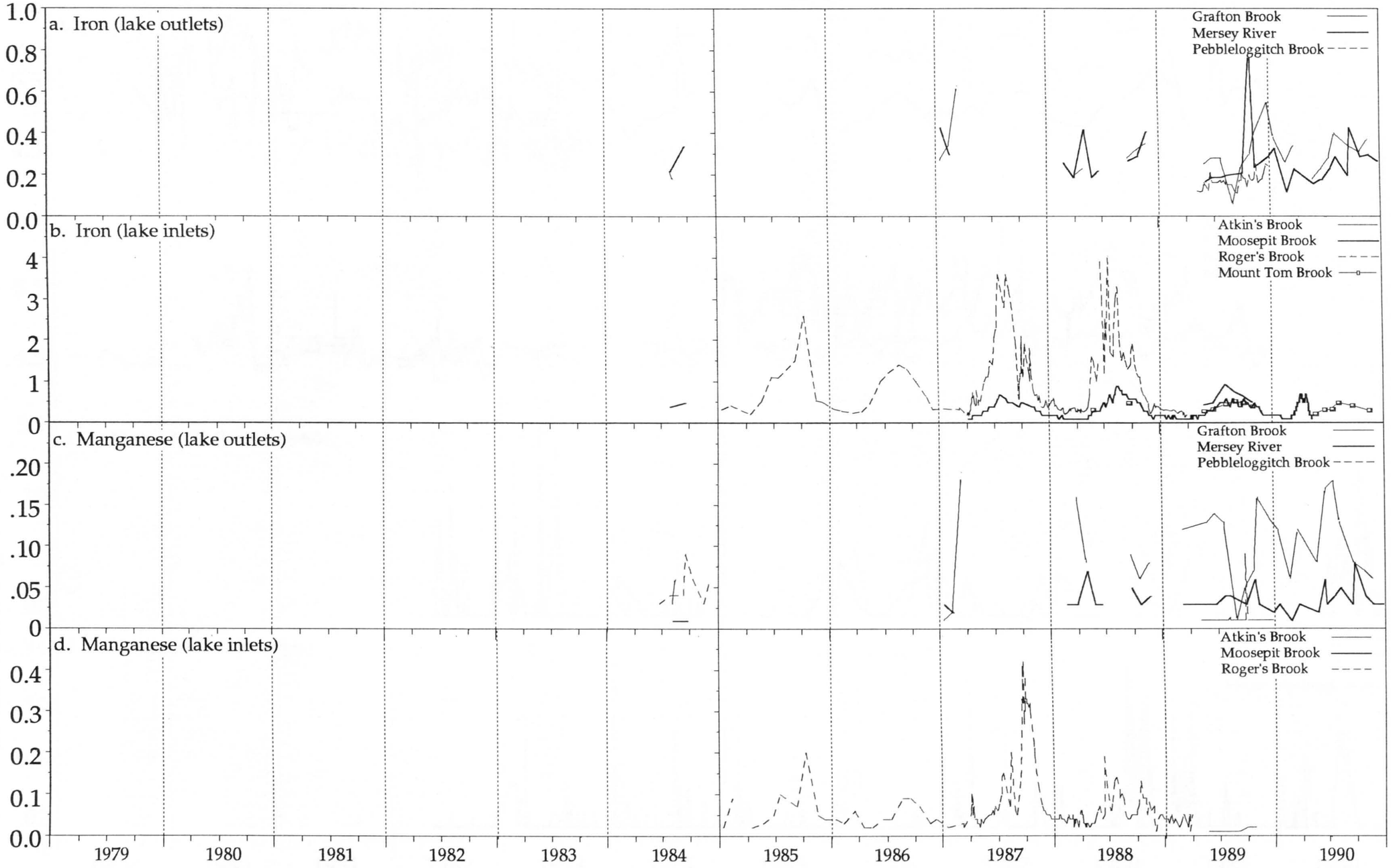


Fig. 17. Stream water concentrations (original data) for: **a.** iron in lake outlets; **b.** iron in lake inlets; c. manganese in lake outlets; **d.** manganese in lake inlets.

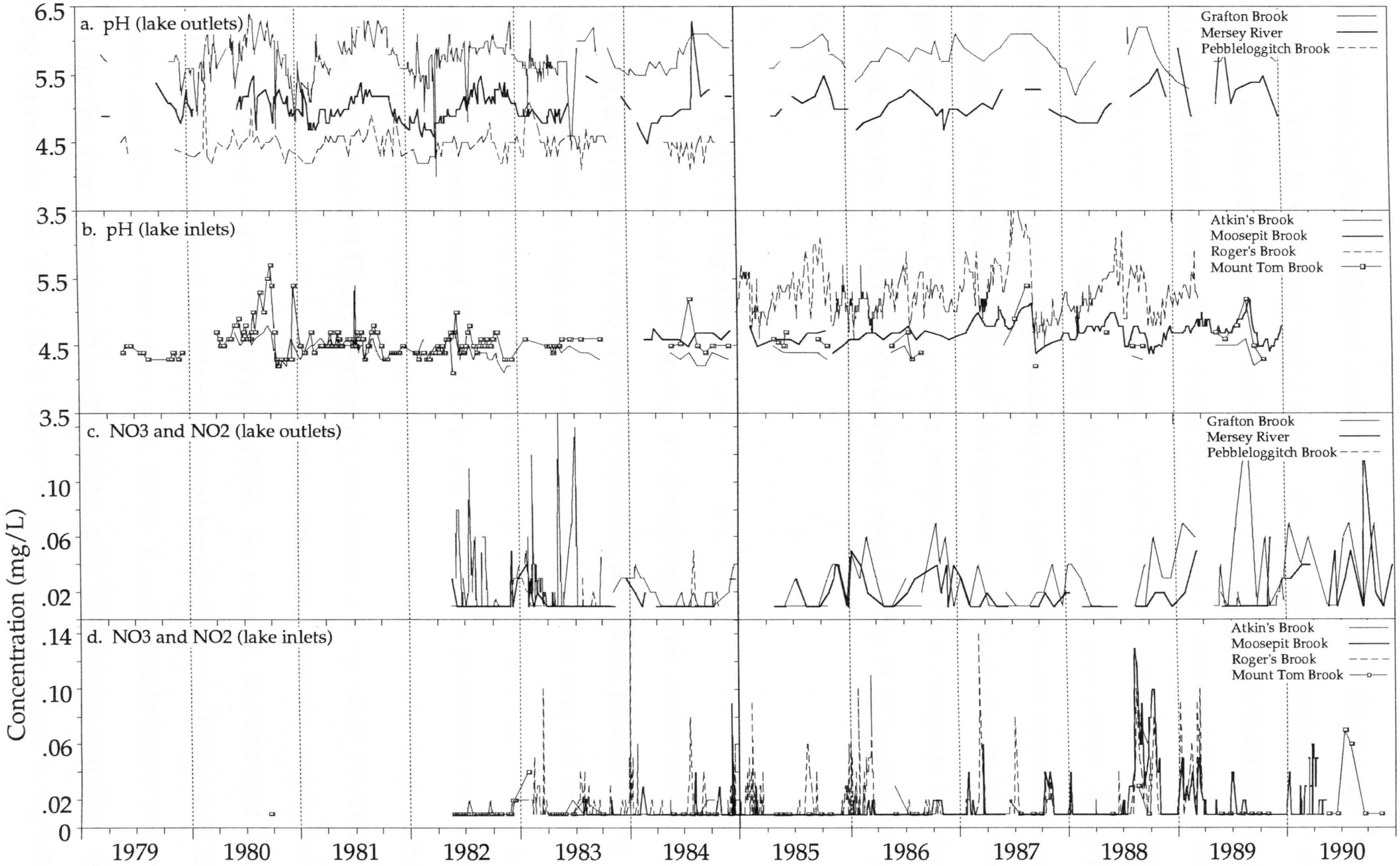


Fig. 18. Stream water concentrations (original data) for: **a.** pH in lake outlets; **b.** pH in lake inlets; **c.** NO3 and NO2 in lake outlets; **d.** NO3 and NO2 in lake inlets.

It is suspected that biological and geological breakdown during the warmer seasons lead to enhanced streamwater ion concentrations during the dry summer periods, and this is followed by flushing of chemicals into streams during fall and early winter (Feller and Kimmins 1979). Additional flushing occurs in spring due to snowmelt. Another general pattern emerges when one categorizes streams as being either lake inlet or lake outlet. Also, the degree to which wetlands predominate in each watershed appears to modify the range and seasonal patterns. Altogether, the trends shown follow distinct patterns: (*i*) the Na, Cl, Mg, and Ca category; (*ii*) the K category; (*iii*) the organic anions, Al, Fe, and Mn category, and; (*iv*) the H, SO_4, and NO_3-N category.

1. Na, Cl, Mg, Ca:

Patterns and levels found for the streamwater concentrations of Na, Cl, Mg, and Ca were likely affected by several watershed processes that consistently led to high streamwater concentrations in late fall and sometimes in winter, and low levels during spring (Fig. 13 and Fig. 14). The large concentrations of Na and Cl in the streams are likely the result of the high atmospheric inputs (Table 7), and the characteristically high mobility of these ions: Na and Cl are frequently not found in vegetation or soils. Na and Cl are very soluble and readily leached from soils, minerals, and bedrock (Henderson *et al.* 1977; Jordan *et al.* 1986). As a result, streamwater Na and Cl concentrations tend to reflect seasonal trends in precipitation (see also Feller and Kimmins 1979; Pinol *et al.* 1992). It was already noted that Na and Cl are the dominant ions in precipitation, and NaCl is the dominant salt in dry deposition, fog and mist (Chapter 5). Furthermore, forest canopies tend to

be very effective interceptors of sea salt particles. Late summer and fall rains tend to wash out salts that may have accumulated in the forest canopies between rain events (Jordan *et al.* 1986). During the summer, salts would be stored in the largely water-unsaturated soils of the watershed, and be retained in the soil by partial absorption on clay mineral surfaces; they could also be stored through vegetative uptake (Neal *et al.* 1990).

The spring lows for Na, Cl, Ca and Mg concentrations in the stream (see also Howell 1989) should be the result of dilution and the fact that dissolved matter content of snow is less than that of rain (Henderson *et al.* 1977). Over the drier summer months, soil solutions tend to be recharged with these ions (Nicolson *et al.* 1987; Kerekes *et al.* 1986b).

Neal *et al.* (1990) found that stream Ca and Mg were highest in very dry summers because of the significant residence time of water in soils and bedrock areas. Soil and bedrock weathering would therefore be the main source of Ca and Mg in the streamwater (Jordan *et al.* 1986; Clair and Freedman 1986).

The seasonal pattern in Roger's Brook, Moosepit Brook and Mersey River found for DOC (measured as organic anion concentrations) was similar to that observed for Ca and Mg. This similarity suggests that Ca and Mg may occur, at least in part, in the form of organic complexes (Clair and Freedman 1986).

In the fall, soil and subsoil moisture and temperature levels should be high. At this time, streamwater Ca and Mg concentrations also reach their highest peaks. This suggests that the fall release of Ca and Mg would be accelerated by increased soil moisture and temperatures by way of accumulation rates of mineral weathering and the decomposition of fresh

litter.

Ca and Mg concentrations tended to be fairly similar for lake outflows from Pebbleloggitch Lake and Beaverskin Lake, but tended to be higher and more variable for lake inlets such as Atkin's Brook (Kerekes *et al.* 1986a). This pattern also held true for all other lake inlet-lake outlet comparisons (Fig. 14). Indeed, Henderson *et al.* (1977) found that increased residence time in lakes reduced Ca concentrations in the outlet streams. In addition, lake outlets tended to have a delayed peak response for Mg, Na, Cl (Fig. 13 and Fig. 14).

The Kejimkujik Lake outlet, which influences the Mersey River, was found to have higher Ca and Mg concentrations than the Pebbleloggitch and Beaverskin Lake outlets. This is, or most likely is, due to differences in soils and bedrock (Clair and Freedman 1986). For example, base-enriched Goldenville greywacke underlies part of the Kejimkujik Lake area. In contrast, base-poor granite is the bedrock of the Pebbleloggitch Lake and Beaverskin Lake watersheds (Gimbarzevsky 1975).

2. K:

K concentrations in the stream were very small, at approximately 0.1 mg/L. There are, however, a few exceptions up to 2.0 mg/L. Little seasonal variation was found (Fig. 15). In other studies, K concentrations in the stream were found to be relatively uniform throughout the year, although some increases were noted with increased discharge rates (Feller and Kimmins 1979; Martin and Harr 1988). High streamwater concentrations for K in spring, and low concentrations in winter, were reported by Pinol *et al.* (1992).

In general, K is a major component of slow weathering soil minerals

(K-feldspars, muscovite, clay). Part of the soluble K enters the soil solution through soil mineral weathering. Another part enters the soil solution through atmospheric deposition and organic matter decomposition (Neal *et al.* 1990). Nevertheless, K concentrations in watershed streams are usually small (Henderson *et al.* 1977; Jordan *et al.* 1986). Several processes could be at work: (*i*) high K uptake rates by the vegetation; (*ii*) high absorption rates of K by clay minerals in the soils, and; (*iii*) high rates of return of K into soil solids through K-fixation (Jordan *et al.* 1986).

3. Organic anions (DOC), Al, Fe, and Mn:

Organic anion concentrations (also referred to as DOC levels) as well as Al, Fe, and Mn concentrations were highest in mid-summer and lowest in winter and spring (Figs. 16 and 17). These ions form a natural concentration because of extensive ion complexation (Clair and Freedman 1986; Neal et al. 1990). In general, Fe, Al, and Mn concentrations in the streamwater were low, and seasonal variations were more evident for lake inlets than for lake outlets.

The delayed lake inlet/outlet peak response for dissolved organic matter and associated cations (Al, Fe, and Mn) from mid-summer towards fall and later, and the lower seasonal variations for Al, Fe, Mn, and organic anions in lake outlets, would likely be due to lake-induced interactions between organic anions and the easily complexed Al, Fe and Mn cations, and the subsequent in-lake loss of dissolved organic matter possibly due to partial flocculation, sedimentation, and in-situ decomposition of organic matter. Howell (1989) reported a similar lake inlet/outlet lag (approximately 3 months), with maximum DOC levels between Moosepit Brook and Mersey River. High order streams (e.g. Mersey River) peaked later. He attributed this

lag to the large storage capacity and long water residence time of high order streams. As a result, Mersey River (longer water residence time) also showed lower DOC values than Moosepit Brook (shorter water residence time).

4. H, SO_4, and NO_3-N:

The seasonal patterns for H mirrored the patterns found for SO_4 and NO_3-N (Figs. 15 and 18). In other words, when H attained lowest concentrations in summer, SO_4 and NO_3-N also attained their minimum concentrations.

Streamwater pH values ranged from 3.75 to 6.5. Highest peaks occurred during summer low flows, lowest peaks during fall and winter (Fig. 18) while the lowest pH levels in streamwater occurred during the cold, wet season when runoff was high. Other studies have shown a similar seasonal pattern (Neal *et al.* 1990; Nicolson *et al.* 1987; Kerekes *et al.* 1982). In catchments with peat deposits, pH levels tended to be one unit lower than catchments free of organic soils (see also Kerekes *et al.* 1982). The lake inlet catchments also showed lower seasonal pH fluctuations, probably a result of organic matter buffering (see also Howell 1989; Kerekes *et al.* 1986a). This is caused by a strong association between H and DOC: high amounts of organic anions maintain low pH values (Kerekes *et al.* 1986a) (Figs. 16 and 18).

It has been reported that geologic sources are not significant contributors to SO_4 in KNP streamwaters (Clair *et al.* 1989). Most of the contributions of SO_4 appear to be due to atmospheric deposition, and some of it is temporarily stored in organic matter (Clair *et al.* 1989; Jordan *et al.* 1986). Approximately 15-30% of SO_4 in precipitation and surface waters is of marine origin (Vet *et al.* 1986). Further increases may be due to washoff of dry SO_4

deposition (Shanley and Peters 1993).

Summer lows in stream SO_4 concentrations can be attributed to high evapotranspiration, low water table and decreased runoff (Ogden 1982; La Zerte and Dillon 1984; Kerekes *et al.* 1982; Shanley and Peters 1993). During base flow periods (summer season), SO_4 is likely retained by mineral soil adsorption. During periods of high flow, SO_4 becomes mobilized in the upper, organic-rich horizons of soil (Shanley and Peters 1993).

In a study conducted in the 1980's, SO_4 concentrations in Atkin's Brook suddenly increased in April when water discharge was still very high and when peatlands thawed. Furthermore, SO_4 levels remained low, likely as a result of biological uptake and transpiration during summer low flow (Kerekes *et al.* 1986a). Skartveit (1980) found that SO_4 concentrations in runoff were inversely related to the productivity of terrestrial vegetation. Similarly, Kerekes *et al.* (1986b) found that drainage water from peatlands contains water low in SO_4 during the growing season.

SO_4 concentrations suddenly increased during late fall when peatlands became water saturated, and discharge rates increased (Kerekes *et al.* 1986b). Even greater SO_4 concentrations in streamwater occurred in winter, and corresponded with maximum DOC concentrations suggesting that sulphur compounds may be accumulated as organic S, or as SO_4 absorbed to organic compounds (Howell 1989; Likens *et al.* 1977; Dovland and Semb 1978; Skartveit 1980).

Newell (1993) found a negative correlation between SO_4 and watershed area, i.e., decreasing SO_4 concentrations with increasing drainage areas. This was also the case for watersheds in the KNP area, where SO_4 concentrations were higher in lake inlets than in lake outlets. In a shorter

term study, Kerekes *et al.* (1986a) reported the general lack of seasonal SO_4 variations in lake water versus the notable seasonal variations found in streamwater.

Nitrate concentrations in lake inlets and outlets tended to be very variable. Highest peaks occurred from late fall throughout the winter. Lowest values occurred during the summer when streamwater pH was highest (Fig. 18). NO_3-N levels in streamwater were very low overall. Similar results were found for a Maritime influenced watershed in Oregon (Pacific Ocean) (Martin and Harr 1988). The minimum NO_3 concentrations found in the summer seasons were likely due to N uptake by the vegetation, and lack of high rates of nitrification in the soils of the area (Henderson *et al.* 1977; Nicolson *et al.* 1987; Emmett *et al.* 1993; Neal *et al.* 1990; Martin 1979).

NO_3-N tended to be most concentrated during periods of increased discharge (Henderson *et al.* 1977), i.e., in late fall and winters following high precipitation events. In addition, nitrate peaks in lakes and in precipitation tended to be synchronized. Newell (1993) also found this pattern.

Peak streamwater nitrate concentrations were presumably caused by episodic injection of high nitrate waters from wet soil pockets adjacent to the streams and lakes during major precipitation events, especially during vegetational dormancy when there is reduced nitrate uptake. The soil pockets referred to will be explained in Chapter 6. In these pockets, nitrate levels were found to be higher than in the drier upland soils. High precipitation events could flush some of the accumulated nitrate ions from these pockets into the streams. For example, Howell (1989) found a short NO_3-N and DOC flush associated with small discharge pulses during dry summer and fall seasons. Also, Riekerk *et al.* (1979) found that runoff water

after dry conditions tends to have elevated ion concentrations.

Lack of slow and steady nitrate injections from the uplands and wetlands into streams and lakes was likely due to a high and persistent rate of N uptake by the vegetation during the growing season. The majority of N output in streamwater is in the organic forms (Henderson *et al.* 1977; Jordan *et al.* 1986). There is also a strong tendency for the newly formed organic matter to resist N mineralization. In part, N uptake starts in the canopy (see Chapter 5). Further nitrate uptake is observed by noting low NH_4-N and NO_3-N levels in the soil solutions, particularly in the dry portions of the uplands soils (details shown in Chapter 6). Absorption of nitrate ions by wetland vegetation is also expected to occur.

NH_4-N concentrations in the streamwater were not measured, probably because they were very low. In general, NH_4 is well retained by soils because of cation retention, partial fixation on clay mineral surfaces, and uptake by terrestrial and aquatic vegetation (Martin 1979). Part of NH_4-N may also be converted to NO_3-N as a result of nitrification.

CONCLUDING REMARKS

As shown, the chemical composition of water changes as water percolates through the canopy and soil and to the streams. These changes are directly related to the sources and sinks of water-soluble constituents that the water encounters as it moves from one area to the next on its way to a stream or a lake. The chemical composition of the water also changes with season, and this in turn illustrates the effects of vegetation on water quality and the in-lake processes for streams located as lake outlets. The causes for all the trends exhibited by the data summarized in this chapter are not fully understood, and require much further investigation. It is reasonable to

suggest, however, that the vegetation and the soils of the area are fully able to absorb amounts of atmospheric NH_4-N and NO_3-N inputs, and that the soils of the area react to the incoming acidity by accelerated soil weathering and related base cation leaching. The presence of dissolved organic matter, which most likely originates from the wetland portions of the watersheds, modify water quality by complexing mineral ions such as Al, Fe, Mn, and perhaps also Ca and Mg. As well, dissolved organic matter buffers streamwater pH such that acid brown waters have a pH near 4 with small seasonal variations. In contrast, clear streams tend to have higher pH values with large seasonal variations.

CHAPTER 5

WATERSHED ION BUDGETS

OBJECTIVES

The main objectives of this chapter are to: (*i*) outline the methods used to describe the derivation of input/output ion fluxes (precipitation, fog input, stream discharge) through upland forest soils in KNP, and; (*ii*) present the results of net watershed ion fluxes and discuss the related dynamics as affected by season, watershed type, vegetation type and stream type (lake inlet versus lake outlet).

METHODS

Atmospheric Inputs

Watershed level ion flux inputs include contributions from rain, snow, fog, and dry deposition. Data for these inputs were compiled for ion flux evaluations as follows. Wet deposition input was volume-weighted using mean monthly ion concentrations multiplied by the precipitation volume (mm). Estimates for fog water and dry deposition were also needed for watershed flux assessment. Mean ion concentrations in water samples obtained from fog water collectors were multiplied with estimated values for forest intercepted fog moisture (see Chapter 3). Dry deposition estimates were obtained by analyzing the monthly contents of a dry deposition sampler (air

sedimentation sampler) that operated from May 1992 to October 1992 (Beauchamp, pers. comm. 1993). The results from this analysis were multiplied by the capture cross-section of the dry deposition sampler and were prorated to the monthly per hectare per year scale.

Stream Outputs

Stream outputs for ions were calculated using mean monthly volume-weighted streamwater ion concentrations. Flux rates for all upland streams (lake inlets) were determined by multiplying ion concentrations with estimated and actual stream discharge rates (see Chapter 3). Ion fluxes (eq/ha/month) were calculated as follows:

For streams with discharge data:

[Mean monthly volume-weighted ion concentrations (mg/L) / eq. wt.]

* [Average Discharge (m^3/sec) / Area (ha)] * [Days per month] * [60*60*24]

For streams without discharge data:

[Mean monthly volume-weighted ion concentrations (mg/L) * 10/eq. wt.]

* [Averaged discharge for either stream inlets or outlets (mm/month)]

Yearly ion fluxes (eq/ha/year) were calculated as average sums of ion fluxes for each year (corrected if the number of months of data < 12).

Wet Deposition (Rain and Snow)

A complete ion budget table for each watershed is presented in Tables 12 and 13. These tables contain two sections: atmospheric inputs (wet deposition, dry deposition, fog deposition) and stream outputs. Wet deposition was dominated by Cl, Na, H, and SO_4 ions. NO_3 inputs were also high with respect to other ions. Wet deposition inputs ranged from 16 to 411 eq/ha/year.

Fog Deposition

Fog water was dominated by Na and Cl ions. This was similar to precipitation chemistry. In fact, fog water contributions of Na and Cl almost equalled the amount deposited as wet inputs. Mg and NH_4 contributions to atmospheric inputs in the form of fog deposition were also significant in relation to wet deposition. Fog deposition of SO_4, NO_3, K, Ca, and H were approximately half the amounts of wet deposition.

Dry Deposition

Dry deposition was dominated by Na and Cl (144 and 142 eq/ha/year, respectively), probably due to salts originating from sea spray. This accounts for approximately 15% of the total atmospheric inputs of Na and Cl. Dry deposition of Mg accounted for 17% of the total atmospheric input. Dry deposition was also a significant contribution to all other species, except H.

Table 12. Mean annual ion budgets and water budget at Kejimkujik National Park, Nova Scotia (Bold numbers give means; light numbers give standard errors of mean (SE))

Years of data		Atmospheric Inputs [eq/(ha a)] NO3	SO4	Organic anions †††	Cl	Na	K	Mg	Ca	H	Al	Fe	Mn	NH4	Water (mm)
1979-1991	Wet dep.	**136** 31	**377** 27	ND	**411** 33	**379** 30	**16** 2.1	**83** 6.4	**63** 12	**395** 39	ND	ND	ND	**67** 5.4	**1391** 40
1992 §§§	Dry dep. †	**12** 5	**19** 10	ND	**142** 62	**144** 65	**3.6** 1.7	**34** 14	**12** 5	**0.26** 0.12	ND	ND	ND	**3.1** 1.4	**0** 0
1992 §§§	Fog dep. ††	**84** 16	**187** 19	ND	**384** 58	**348** 53	**8.1** 1	**81** 12	**27** 5	**154** 24	ND	ND	ND	**57** 6.3	**99.5** §§
	Total	**232** 52	**583** 56	ND	**937** 153	**871** 148	**28** 4.8	**198** 32	**102** 22	**549** 63	ND	ND	ND	**128** 13	**1491** 40(+)
Lake Inlets	Years of data	Stream Outputs [eq/(ha a)]													
Moosepit Brook	1983-89	**4.6** 0.4	**271** 19	**307** 34	**562** 43	**635** 42	**57** 2.9	**243** 18	**226** 16	**119** 35	**96** 8	**36** 3.6	**3.5** 0.3	ND	**805** 42
Roger's Brook	1983-89	**8.6** 1.7	**565** 17	**247** 15	**1114** 38	**1161** 31	**51** 1.6	**436** 6	**408** 6	**69** 2	**117** 5	**178** 4.5	**14** 1.2	ND	**792** 95
Atkin's Brook	1980-85, 89	**4.5** 0.3	**255** 39	**505** 23	**711** 74	**824** 75	**38** 5.1	**253** 18	**210** 15	**253** 30	**101** §	**73** §	**1.7** §	ND	**792** 95
Mount Tom Brook (below rapids)	1980-85, 89	**4.8** 0.8	**236** 29	**330** 20	**810** 91	**957** 137	**34** 3.7	**234** 17	**190** 14	**170** 20	**112** §	**38** §	**2** §	ND	**792** 95
Mount Tom Brook (Kejimkujik Lake)	1979-85, 89	**4.5** 0.5	**306** 51	**386** 56	**866** 82	**920** 84	**68** 18	**308** 44	**194** 17	**255** 35	**130** §	**48** §	**1.5** §	ND	**792** 95
Pine Marten Stream	1991	ND	**396**	ND	**678** §	**778** §	**20** §	**254** §	**189** §	**35** §	**66** §	**52** §	**21** §	ND	**713** §
Beaverskin Lake inlet	1981-82	ND	**276** §	**327** §	**1115** 58	**1129** 4.7	**71** 22	**286** 12	**210** 14	**292** 30	ND	ND	ND §	ND	**743** 32
Mersey River (Mill Falls)	1972-73, 79-89	**10.3** 1.7	**350** 22	**176** 27	**1041** 57	**1006** 41	**62** 5.4	**308** 13	**340** 22	**141** 20	**138** 10	**53** 4.9	**5.4** 0.4	ND	**779** 34
Lake Outlets															
Mersey River (George Lake)	1969-73, 79-89	**11.3** 1.9	**389** 34	**159** 13	**917** 62	**913** 61	**83** 5.1	**293** 17	**288** 22	**95** 10	**129** 33	**65** 18	**8.5** 2.4	ND	**645** 26
Grafton Brook	1979-89	**14.1** 2.7	**362** 33	**113** 11	**1307** 124	**1224** 118	**43** 4.6	**372** 36	**374** 24	**20** 2	**71** 15	**79** 7.8	**##** 0.9	ND	**743** 32
Pebbleloggitch Brook	1979-84, 89	**4.8** 0.4	**268** 26	**235** 27	**792** 76	**853** 84	**46** 4.9	**218** 21	**138** 16	**291** 27	**131** §	**31** §	**1.9** §	ND	**743** 32
Beaverskin Brook	1979-85, 89	**7.1** 1.0	**208** 29	**117** 27	**822** 69	**821** 80	**41** 4.7	**217** 22	**140** 16	**37** 5	**19** §	ND	**3.0** §	ND	**743** 32
Average (lake inlets only)		**6.2** 0.9	**332** 30	**325** 29	**862** 63	**926** 59	**50** 8.4	**290** 18	**246** 15	**167** 25	# **109** 8	**68** 4.3	**7.1** 0.6		**776** 69.71

† Dry deposition collection at Cape Forchu
†† Fog collection data at Cape Forchu combined with the ForHyM fog drip estimate at Kejimkujik National Park
§ insufficient information (data available for only one year)
§§ insufficient information (mean fog estimate is obtained from cumulative water balance)
$$$ SE based on within year variations
††† Organic anions estimated using two SO4 measurements
ND no data

Table 13. Total N, organic N, dissolved organic carbon (DOC), and ion balances for various watersheds at Kejimkujik National Park. (Bold numbers give means; light numbers give standard errors of mean (SE))

	pH (volume weighted)	**Total N** eq/ (ha a)		**Dissolved Organic N** mg/l	**DOC** mg/l	**C/N**	**Ion balance** Anion Sum (mg/l)	Cation Sum (mg/l)	Δ mg/l
Wet dep.	**4.55**	**203.1**					**924**	**936**	**12**
Dry dep.		**14.9**					**174**	**195**	**21**
Fog dep.	**3.81**	**141.3**					**655**	**618**	**-37**
Total		**359.3**					**1753**	**1749**	**-4**
Lake Inlets									
Moosepit Brook	**4.83**	**46**	5	**0.072**	**21**	**292**	**1452**	**1415**	**37**
Roger's Brook	**5.12**	**71**	7	**0.110**	**16**	**144**	**2182**	**2434**	**-253**
Atkin's Brook	**4.49**	**79**	7	**0.132**	**39**	**293**	**1981**	**1754**	**227**
Mount Tom Brook (below rapids)	**4.67**	**78**	10	**0.129**	**24**	**183**	**1711**	**1736**	**-26**
Mount Tom Brook (Kejimkujik L.)	**4.50**	**76**	9	**0.126**	**29**	**233**	**1949**	**1924**	**25**
Pine Marten Stream	**5.31**	**56**	ND	ND	ND	ND	**ND**	**1276**	**ND**
Beaverskin Lake inlet	**4.41**	ND	ND	ND	**26**	ND	**ND**	**1988**	**ND**
Mersey River (Mill Falls)	**4.74**	**52**	5	**0.075**	**12**	**165**	**1753**	**2054**	**-300**
Lake Outlets									
Mersey River (George Lake)	**4.83**	**63**	7	**0.112**	**11**	**97**	**1635**	**1875**	**-240**
Grafton Brook	**4.69**	**62**	7	**0.090**	**7**	**72**	**1909**	**2210**	**-301**
Pebbleloggitch Brook	**4.49**	**84**	10	**0.149**	**19**	**124**	**1535**	**1710**	**-175**
Beaverskin Brook	**5.39**	**57**	7	**0.094**	**7**	**75**	**1271**	**1318**	**-47**
Average (inlets)	**4.76**	**65**	7	**0.107**	**24**	**218**	**1838**	**1823**	**-48**
Average (outlets)	**4.85**	**67**	8	**0.111**	**11**	**92**	**1588**	**1778**	**-191**

ND no data

Stream Outputs

Na and Cl had the highest stream outputs for all watersheds ranging between 562 to 1307 eq/ha/year (Table 13). Mean annual outputs for these elements approximated the atmospheric inputs. Grafton Brook, Roger's Brook, Beaverskin Lake inlets, and Mersey River (Mill Falls) had the highest stream outputs for Na and Cl. Moosepit Brook, Atkin's Brook, Pebbleloggitch Lake, and Beaverskin Lake had the lowest streamwater outputs.

Streamwater outputs of NO_3 were very small, with highest values for lake outlets including Mersey River. Roger's Brook was an exception, with NO_3 output exceeding all other lake inlets (excluding Mersey River).

Stream outputs for H varied considerably, ranging from 20 to 292 eq/ha/year. This reflected the different levels of acidity for all the streams. For example, Grafton Brook, Beaverskin Brook, and Roger's Brook had low H outputs (high pH). Pebbleloggitch Lake, Beaverskin Lake inlet, Mount Tom Brook, and Atkin's Brook had high H outputs.

All watersheds had streamwater outputs of SO_4 in the range of 208-565 eq/ha/year. Roger's Brook had the highest SO_4 outputs (almost balancing with atmospheric inputs). Beaverskin Brook and Mount Tom Brook (below rapids) had the lowest SO_4 outputs.

Roger's Brook and Grafton Brook had the highest Ca and Mg outputs to the stream. Ca outputs were lowest for Mount Tom Brook, Pine Marten Brook, Pebbleloggitch Brook, and Beaverskin Brook. Mg outputs were lowest for similar watersheds, with the addition of low outputs found for Moosepit Brook and Atkin's Brook.

Mersey River (George Lake), Beaverskin Lake inlet, Mount Tom Brook, and Mersey River (Mill Falls) had the greatest output of K to the

stream, but all K outputs were very small (ranging from 34-83 eq/ha/year).

There was insufficient data for an accurate assessment of Fe, Al, and Mn stream outputs. From the data available, Roger's Brook and Grafton Brook had the highest Fe and Mn outputs. Moosepit Brook and Pebbleloggitch Brook had the lowest Fe and Mn output. Al outputs to the stream were highest for Mersey River and Roger's Brook. Grafton Brook had the lowest output of Al to the stream.

Organic anion outputs to the streamwater were greatest for Atkin's Brook, Mount Tom Brook, Moosepit Brook, and Pebbleloggitch Brook, reaching values up to 505 eq/ha/year. Grafton Brook, Beaverskin Brook, and Mersey River had the lowest organic anion outputs to the streamwater.

Watershed Budgets (Net Outputs)

Hydrogen, S and N budgets were positive, thereby indicating that the watersheds were actively absorbing atmospheric H, S and N deposition (N deposition = NO_3 + NH_4 deposition; N output = NO_3 loss + organic N loss; see Tables 12 and 13). The positive net budgets for H mean that the watersheds were able to buffer the incoming acidity. This, however, occurred only in part, because there were significant streamwater H ion losses as well, i.e. the water of some of the streams was fairly acidic.

The positive budgets for N, and the very low N levels in the streams mean that the watersheds were highly undersaturated with respect to N. From this, it follows that nitrogen uptake rates by the vegetation were high, and subsequent N mineralization rates were low. Net watershed retention of S may mean that S is coabsorbed with N in order to meet the nutritional demands of the aggrading biomass within the watersheds. Continued

absorption of S in the soils of the area was also likely. In past assessments, calculated net budgets for S were only slightly positive (Kerekes *et al.* 1989).

The mobility of SO_4 and NO_3-N through the watersheds is obviously restricted by vegetational ion uptake in the summer, and subsequent winter release on account of S and N mineralization. There is also the mechanism of SO_4 absorption within the B horizons of the highly podsolized soils of the area (Arp *et al.* 1988). The H ion is associated with SO_4 and NO_3-N movement through the watershed because soil acidity is in part neutralized by vegetative SO_4 and NO_3 ion uptake, and in part, by SO_4 absorption within the soil.

The input/output budgets for Na and Cl were balanced in almost all cases, thereby indicating that the watersheds were saturated with respect to atmospheric NaCl deposition. Note that this balance was particularly dependent on the inclusion of fog drip and dry deposition. There were, however, significant variations among the watersheds. These differences were likely related to the actual precipitation pattern and fog interception as possibly affected by terrain and topography.

Net budgets for K, Mg, and Ca were all negative. Net losses of base cations result from soil weathering, and soil weathering was likely stimulated by soil acidification and H retention. The major movements of these ions through the watershed likely occurred through direct runoff, ion exchange, and in part, through the sequence of vegetative ion uptake and nutrient cycling.

Note that atmospheric inputs of H ions as well as the vegetational uptake of NH_4 ions and of base cations must contribute to soil acidification. In fact, the net loss of base cations from the basins approximated the acid

cation amounts received through atmospheric deposition (i.e., $H+NH_4 \approx$ Ca+Mg+K+Na losses; see Table 13). Furthermore, the total cation outputs exceeded the watershed inputs only by a slight margin. Hence, soil weathering at Kejimkujik appears to be quite limited beyond acid-induced stimulation.

Net budgets for Al, Fe, and Mn were also all negative: atmospheric inputs for these elements (data not available) should be small to negligible. Watershed outputs for the elements would be due to soil acidification and related soil weathering and subsequent mobilization of Al and possibly of Fe as well. These elements, however, are also highly complexed by organic matter, and likely remain so as the water percolates through the uplands and the wetlands.

The mobility of Al, Fe and Mn through the watersheds appear to be affected by the summer release of organic matter (including organic N) from wetland and upland soils. In this regard, soil organic matter seems to serve both as a sink and as a source for easily complexed ions such as Al, Fe, and Mn.

Organic anion and organic N (= total N - NO_3 - NH_4-N) are highest in primary upland streams that flow through extensive wetland (peatland) formations, some of which are overgrown with dense grass vegetation (Tables 12 and 13). Also, there is a drop in dissolved organic matter (DOM) concentrations from lake inlets to lake outlets, and the C/N ratio of the dissolved organic matter decreases at the same time (from approximately 200 to 100) (Table 13). Wood and Rubec (1989) reported very high C/N ratios in the surface water and streamwaters of the area, and have further reported that C/N ratios of the organic matter in the originating bogs and fens range from 30 to 50. All of this suggests that microbiological activities in the wetlands

and surface waters of this area are high, especially during summer. In wetlands next to the streams and lakes, dissolved organic matter with a low C/N ratio is generated. En route through the lakes, a considerable portion of this organic matter is converted to CO_2. Times of low flow rates enhance the extent of this conversion (Kerekes 1986).

Other processes that possibly play a minor part with the lakes are flocculation and sedimentation, and dilution as a result of direct rain and snow catch by the lakes. Flocculation and sedimentation likely play a minor role because flocculating elements such as Al, Fe, and Ca pass through the lakes with little or no loss. The rain-induced dilution aspect has been discussed by Kerekes (1974).

CONCLUDING REMARKS

Atmospheric deposition, vegetative uptake and retention, and soil weathering rates all contribute to ion budgets for watersheds in Kejimkujik National Park. The uplands and wetlands soils and vegetation differ in their ability to absorb and retain N, therefore affecting N budgets for watersheds with high percentages of wetlands. Altogether, the watersheds of the area are strongly N undersaturated, partially saturated with respect to H ions and S, and are fully saturated with respect to Na and Cl. The soils appear to be effectively retaining K and NH_4 ions, presumably due to vegetative uptake, and possibly also by way of clay mineral fixation.

Stream outputs for N were considerably higher in the streamwaters of other hardwood/mixedwood forested watersheds, e.g. the Nashwaak area in Central New Brunswick (Jewett *et al.* 1994), and the Turkey Lakes watersheds in Western Ontario (Yin *et al.* 1993), than at Kejimkujik. The

cause for the very low N streamwater output at KNP was likely related to the generally aggrading conditions of the forest stands of this area, and the now dominant grass (sedge) vegetation in some of the wetlands and along most stream corridors. It is suspected that high rates of atmospheric N deposition encourage and stimulate the growth of nitrophilic vegetation, especially that of tall grass species. With continuing atmospheric N inputs, it is possible that these grasses would gradually replace the shrubby species in some of the wetlands. In the past, grassy wetlands at the Park were probably not as extensive as they are now. The gradual spreading of grasslands into former heathlands is now recognized as a major environmental problem in many European countries. Compared to KNP, wetland vegetation was absent at the Turkey Lakes site due to steep sloped terrain, or was present but occurred in the form of shrubs and conifers at the Nashwaak site.

The watersheds of the area tend to be very conservative in terms of base cation leaching, i.e. soil weathering rates are low. Consequently, surface waters have low Ca and Mg concentrations, watershed ion charge outputs hardly exceed atmospheric inputs and net acid inputs approximate net base cation outputs.

CHAPTER 6

CHEMICAL COMPOSITION OF SOIL WATER SOLUTION EXTRACT IN KEJIMKUJIK NATIONAL PARK

INTRODUCTION

The preceding chapters of this thesis have dealt with analysis and examination of water which is deposited by the atmosphere (through precipitation, dry deposition, fog deposition), received by the forest floor (throughfall and stemflow), and lost from the general area due to stream discharge. In this chapter, special attention is given to the water as it exists in the soil solutions of upland and lowland sites. For that reason, a special field investigation was done to sample the soils and the soil solutions of the area of the KNP, with the overall sampling effort confined to the watershed areas that have been delineated in the preceding chapters. The investigation was necessary for several reasons: (*i*) to bridge the gap between the above-ground deposition data and the accumulated records for stream discharge; (*ii*) information regarding the chemical composition of the soil solution was not available, and; (*iii*) much of the ion load in the stream discharge should originate from the contact between the soils and the percolating water. It is reasonable to suggest that the type of soil, and its natural association with the vegetation that the soil supports, affects the chemical composition of the percolating water in a special, site-specific manner. Surprisingly, very little documented information regarding the association between soil type and

percolating water is available.

The overall purpose of the field investigation reported in this chapter is to document what changes, if any, occur in the percolating water along natural down-hill seepage pathways, and to analyze these changes in terms of basic soil types, i.e. well-drained upland soils (mostly podzols) versus imperfectly to poorly drained wetland soils (mostly gleysols). The latter were located near stream banks, along ephemeral water paths, or seepage sites on upland areas. The specific objective for this chapter is to present and to discuss the results so obtained. The ions addressed are, once again, Ca, Mg, Cl, Na, Fe, K, Mn, Al, NO_3-N, SO_4, and H.

METHODS

Field Sampling

Seven watersheds in and near KNP were visited in August 1993. Soil samples were taken during a long summer drought period. The sampled watersheds included Moosepit Brook, Roger's Brook, Atkin's Brook, Mount Tom Brook, Pine Marten Brook, Pebbleloggitch Lake, and Beaverskin Brook (Fig. 1). Soil profiles were examined, and samples were collected from each major horizon for later analysis of water-extractable ion concentrations.

Laboratory Analysis

Laboratory analysis included measurements for water soluble Cl, NO_3-N, SO_4, Fe, K, Na, Mn, Ca, Mg, Al (5 g of moist soil in 10 ml of extract, 2.5 g of moist organic soil in 15 ml of extract), and pH. Ca, Mg, K, Na, Fe, and Al concentrations were determined by atomic absorption spectrophotometry (McKeague 1978). Cl, SO_4 and NO_3-N concentrations were determined by

ion-exchange chromatography. Extraction was done by shaking the soil/water samples for 24 hours. Subsequently, the samples were centrifuged to separate the resulting solution from the soil solids. Samples containing high amounts of organic matter were colored from yellow to dark brown, depending on the amount of organic matter that remained in solution following centrifugation. No attempt was made to filter the organic matter from these solutions before ion analysis. This, in a way, was done to simulate the actual amounts of ions that are potentially mobilized from the soil on account of water percolation alone. Such a mobilization would include those ions that would move together with the organic matter through the soil.

RESULTS AND DISCUSSION

The main soil types for the forested upland sites were Orthic Humo-Ferric Podzols. The lowland soils were mainly gleysols, most of which were associated with grassy vegetation and thick organic soil layers. Summaries of the various soil characteristics found in each watershed are presented in Table 14. To illustrate patterns, Appendix V (A-T) is a graphical representation of soil profiles (depth and ion concentration) for each watershed.

Table 14. Summary of soil characteristics measured in the field

SOIL SITE	HORIZON	DEPTH (cm)	pH	TEXTURE	SOIL SITE	HORIZON	DEPTH (cm)	pH	TEXTURE	SOIL SITE	HORIZON	DEPTH (cm)	pH	SOIL SITE	HORIZON	DEPTH (cm)	pH
LAKE INLETS																	
Moosepit Brook	F	3-1	3.18		**Moosepit Brook**	FH	<1cm	2.83		**Moosepit Brook**	F	12.5-0	3.35	**Moosepit Brook**	F	10-3	3.12
Clearing	Ae	0-2	3.16	SiL	**Forested**	Aej	0-3	3.15	L	**Lowland #1**	Ah	0-2	3.56	**Lowland #2**	H	3-0	3.31
	Bf1	2-14	4.02	L		Bf1	0-12	4.57	L		Bg	2-18	4.41		Ah	0-5	3.49
	Bf2	14-28	4.65	SL		Bf2	12-24	4.84	L						Bg	5+	4.29
	BC	28-42	4.95	SL		BC	24-42	5.01	SL								
	C	42+	4.97	SL		C	42+	4.96	SL								
Roger's Brook	L	4-3	3.81		**Roger's Brook**	L	3-2			**Roger's Brook**	F	2-0	5.43	**Roger's Brook**	F	2-0	3.61
Hemlock Ridge	F	3-0	3.81		**Pine Ridge**	F	2-0	3.48		**Lowland #1**	Ah	0-2	4.91	**Lowland #2**	Ahe	0-5	4.16
	Ah	0-5	4.07	L		Ahe	0-5	4.01	L		Bg	2+	4.54		Bg	5-25	4.22
	Bf1	5-12	4.27	L		Bf1	5-10	4.29	L								
	Bf2	12-70	4.73	L		Bf2	10-32	4.64	L								
	Aej	12-20	3.89	SiL		BC	32+	4.61	LS								
	BC	70+		SL													
Atkin's Brook	L	3.5-3.0	3.17		**Atkin's Brook**	F	4-0	3.21		**Atkin's Brook**	F	5-0	2.88				
South Ridge	F	3.0-0	3.17		**North Ridge**	Ae	0-4	3.28	L	**Lowland #1**	Ae	0-4	3.33				
	Ae	0-2	3.35	L		Bf1	4-16	4.25	L		Bg	4-19	3.34				
	Bf1	2-14	4.71	L		Bf2	16-30	4.66	L		Bcg	19+	3.74				
	Bf2	14-29	4.61	L		BCj1	30-50	4.30	SL								
	BC1	29-49	4.57	SL		BC2	30-50	5.50	SL								
	BC2j	29-39	4.29	SL		C	50+	5.13	SL								
	C	49+	5.06	SL													
Mount Tom Brook	L	4.5-4	3.00		**Mount Tom Brook**	L	2.5-2	3.39		**Mount Tom Brook**	F	25-10	3.21	**Mount Tom Brook**	F	45-30	3.59
West Ridge	F	4-2	3.00		**East Ridge**	F	2-0	3.39		**Lowland #1**	H	10-0	3.31	**Lowland #2**	H	30-0	3.52
	H	2-0	3.00			Aej	0-3	3.38	L		Ah	0-30	3.69		Ah	0-15	3.72
	Ae	0-2	3.20	SL		Bf1	3-18	4.43	L		Bg	30+	4.41		Bg	15+	4.05
	Bf1	2-14	4.23	SL		Bf2	18-48	5.23	L								
	Bf2	14-34	4.57	SL		BC	48-75 +	4.81	L								
	BC1	34-60	4.81	SL													
	BC2	45-50	4.32	SL													
Pine Marten	L	9.5-9.0			**Pine Marten**	F	4-0	3.14		**Pine Marten**	FH	4-0	3.31	**Pine Marten**	F	4-1	3.53
Brook	F	9-4	3.11		**Brook**	Aej	trace			**Brook**	Ae	<1	3.31	**Brook**	H	1-0	3.57
Top Ridge	H	4-0	2.95		**Low Ridge**	Bf1	0-20	4.71	SiL	**Lowland #1**	Bf1	0-25	4.62	**Lowland #2**	Ah Top	0-15	4.24
	Ae	0-3	3.46	SL		Bf2	20-40	4.86	SiL		Bf2	25+	4.76		Ah Bot	15-35+	4.31
	Bf1	0-15	4.50	L		BC	40+	4.74	L								
	Bf2	15-35	4.42	L													
	BC	35-55	4.63	SL													
	C	55+	4.53	SL													
LAKE OUTLETS																	
Pebbleloggitch L.	L									**Pebbleloggitch L.**	F	45-20	3.12				
	F	5-0.5								**Lowland #1**	H	20-0	3.28				
	H	<0.5	3.06														
	Ae	0-12	3.30	SL													
	Bf1	12-22	4.95	L													
	Bf2	22-32	5.25	SL													
	BC	32-44	5.30	SL													
	C	44+	4.90	SL													
Beaverskin Brook	F	3-0								**Beaverskin Brook**	F		3.31				
Ridge	H	trace	2.85							**Lowland #1**	H	20-0	3.53				
	Ae	0-12	3.15	SL													
	Bf1	12-22	4.74	SL													
	Bf2	22-34	4.73	SL													
	BC	34-46	4.71	SL													
	C	46+	4.61	SL													

Water Soluble Ion Concentrations

Figures 19 and 20 illustrate the typical chemical characteristics in soil (chemical profiles) for watersheds in KNP. During the summer drought, concentrations of NO_3-N and SO_4 were typically highest in the forest floor, and had a secondary peak in the mineral soil at the point where seepage water percolates laterally through the soil on top of a compacted subsoil layer. This drought precedes the small and short NO_3-N peak in streamwater when precipitation increases in the fall (Howell 1989; Riekerk *et al.* 1979; see also Chapter 4). Studies at the Turkey Lakes (Foster *et al.* 1989) and Nashwaak Experimental Watershed (Jewett *et al.* 1994) also displayed this phenomenon for NO_3-N. Following wet weather, such profiles would likely not be as pronounced, or would likely disappear altogether.

Table 15 lists average ion concentrations for the soil solutions. For comparison, mean August bulk precipitation and August water-soluble ion concentrations in streamwater are also listed. The results for the soil solutions are also graphically displayed in Appendix V. In these plots and in this Table, upland soils are grouped as follows: (*i*) soils under mainly mixedwood forests (Atkin's Brook, Mount Tom Brook, Pine Marten Brook, and Pebbleloggitch Lake), and; (*ii*) soils under mainly softwood forests (Beaverskin Brook, Moosepit Brook, and Roger's Brook). From all of this, it appears that the soil solution ion concentrations generally followed the same pattern: ion concentrations were highest in the top organic horizons (or forest floor). Soils sampled in low-lying and moist to wet areas had higher concentrations than any of the upland soils. The patterns found can be grouped as follows.

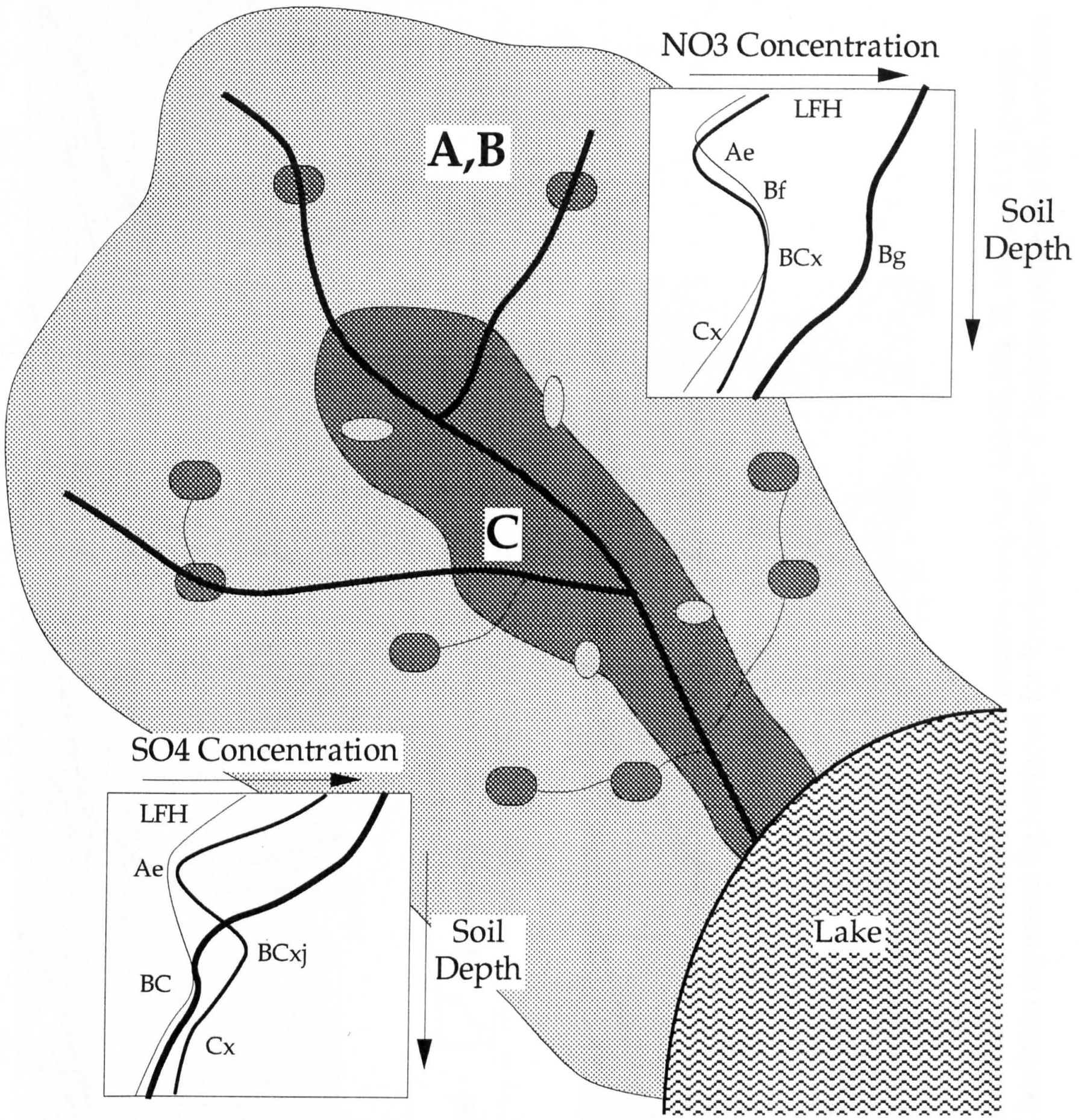


Fig. 19. Schematic diagram of watersheds in KNP, depicting NO3 and SO4 concentrations of upland and lowland soil profiles. Concentrations are typically highest in the forest floor, and have a secondary peak in the mineral soil at the point where seepage water percolates laterally through the soil on top of a compacted subsoil layer.

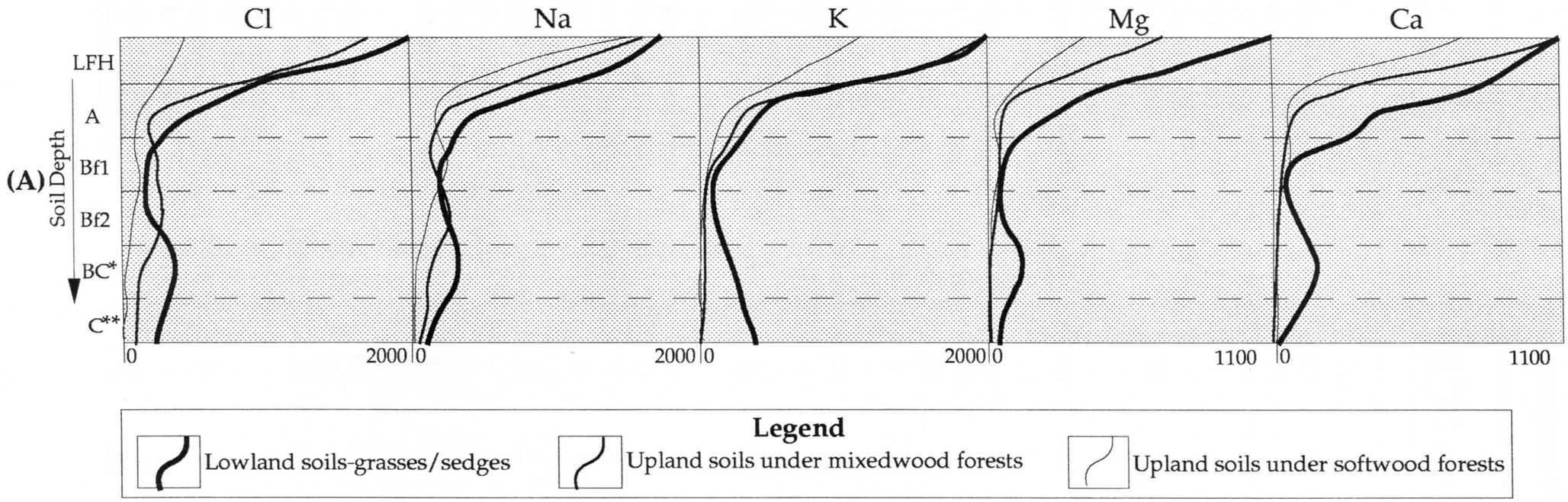


Fig. 20. General soil profile trends found for water-soluble ion concentrations (μeq/L): (A) Cl, Na, K, Mg, and Ca group; (B) Al, Mn, and Fe group. Note: * BC horizons represent Bg horizons for lowland soils; ** C horizons represent BC horizons for lowland soils.

Table 15. Means, standard errors, and numbers of samples for water-soluble ion concentrations in soils measured in KNP

Stratum	Lowland Soils			Upland Soils Mixedwood Forest †			Upland Soils Softwood Forest ††		
	mean	*std err*	*n*	*mean*	*std err*	*n*	*mean*	*std err*	*n*
	μeq/L								
NO3									
Bulk precipitation*	14	1.5	13	14	1.5	13	14	1.5	13
Organic horizons	348	178	11	30	11	4	21	18	3
A horizons	500	221	5	8	4	4	7	3	3
Bf1 horizons	75	-	1	18	2	4	30	16	3
Bf2 horizons	101	-	1	29	10	4	31	16	3
Bg horizon	15	10	4	-	-	-	-	-	-
BC horizons	0	-	1	25	4	4	17	10	3
C horizons	-	-	-	20	4	3	8	8	2
Stream Output**	1.2	0.4	117	1.2	0.6	52	1	0.29	65
SO4									
Bulk precipitation	34	4	13	34	4	13	34	4	13
Organic horizons	3161	386	11	1700	352	4	827	130	3
A horizons	880	309	5	174	47	4	198	119	3
Bf1 horizons	238	-	1	314	11	4	234	84	3
Bf2 horizons	172	-	1	1021	417	4	221	30	3
Bg horizon	414	129	4	-	-	-	-	-	-
BC horizons	182	-	1	291	46	4	506	294	3
C horizons	-	-	-	212	14	3	177	31	2
Stream Output	38	6	118	42	6	53	32	20	65
H									
Bulk precipitation	41	5	13	41	5	13	41	5	13
Organic horizons	48	11	11	55	18	4	88	35	3
A horizons	22	8	5	46	4	4	50	20	3
Bf1 horizons	2	-	1	2.9	0.8	4	4.1	1.1	3
Bf2 horizons	2	-	1	1.6	0.4	4	1.9	0.1	3
Bg horizon	15	10	4	-	-	-	-	-	-
BC horizons	18	-	1	1.8	0.4	4	1.8	0.4	3
C horizons	-	-	-	1.7	0.7	3	1.8	0.7	2
Stream Output	1.7	0.1	126	2.5	0.0	61	0.8	0.1	65
K									
Bulk precipitation	0.7	0.1	13	0.7	0.1	13	0.7	0.1	13
Organic horizons	2041	378	11	3293	560	4	1052	170	3
A horizons	202	21	5	146	37	4	95	36	3
Bf1 horizons	86	-	1	114	34	4	93	42	3
Bf2 horizons	66	-	1	39	5	4	57	33	3
Bg horizon	110	26	4	-	-	-	-	-	-
BC horizons	225	-	1	41	10	4	43	18	3
C horizons	-	-	-	33	10	3	45	11	2
Stream Output	8	2	128	6	2	63	9	2	65

Table 15. (Continued)

Stratum	Lowland Soils mean	Lowland Soils std err	Lowland Soils n	Upland Soils Mixedwood Forest † mean	Upland Soils Mixedwood Forest † std err	Upland Soils Mixedwood Forest † n	Upland Soils Softwood Forest †† mean	Upland Soils Softwood Forest †† std err	Upland Soils Softwood Forest †† n
	----------μeq/L----------								
					Ca				
Bulk precipitation	3.4	0.8	13	3.4	0.8	13	3.4	0.8	13
Organic horizons	12665	2685	11	7711	1934	4	3327	755	3
A horizons	3476	1544	5	129	23	4	101	56	3
Bf1 horizons	36	-	1	120	19	4	148	37	3
Bf2 horizons	81	-	1	114	28	4	60	18	3
Bg horizon	801	418	4	-	-	-	-	-	-
BC horizons	69	-	1	72	18	4	47	8	3
C horizons	-	-	-	68	16	3	64	16	2
Stream Output	37	5	128	33	6	63	42	4	65
					Mg				
Bulk precipitation	2.5	0.5	13	2.5	0.5	13	2.5	0.5	13
Organic horizons	9828	1494	11	3921	727	4	1535	131	3
A horizons	2292	1116	5	111	33	4	62	32	3
Bf1 horizons	106	-	1	124	10	4	135	33	3
Bf2 horizons	76	-	1	103	23	4	92	19	3
Bg horizon	424	221	4	-	-	-	-	-	-
BC horizons	112	-	1	51	10	4	78	30	3
C horizons	-	-	-	51	12	3	55	20	2
Stream Output	42	5	128	41	6	63	45	4	65
					Na				
Bulk precipitation	11	2	13	11	2	13	11	2	13
Organic horizons	1606	192	11	2634	836	4	1753	563	3
A horizons	287	83	5	92	24	4	76	21	3
Bf1 horizons	49	-	1	72	4	4	302	97	3
Bf2 horizons	58	-	1	167	57	4	61	13	3
Bg horizon	139	31	4	-	-	-	-	-	-
BC horizons	104	-	1	67	9	4	51	8	3
C horizons	-	-	-	65	14	3	38	1	2
Stream Output	134	9	128	134	5	63	134	13	65
					Cl				
Bulk precipitation	11	2.5	13	11	2.5	13	11	2.5	13
Organic horizons	2088	201	11	1574	310	3	371	63	3
A horizons	397	77	5	106	30	4	114	43	3
Bf1 horizons	84	-	1	229	53	4	191	7	3
Bf2 horizons	72	-	1	231	82	4	129	9	3
Bg horizon	164	65	4	-	-	-	-	-	-
BC horizons	135	-	1	87	18	4	114	36	3
C horizons	-	-	-	66	10	3	73	17	2
Stream Output	115	14	128	113	15	63	118	13	65

Table 15. (Continued)

Stratum	Lowland Soils mean	Lowland Soils std err	Lowland Soils n	Upland Soils Mixedwood Forest † mean	Upland Soils Mixedwood Forest † std err	Upland Soils Mixedwood Forest † n	Upland Soils Softwood Forest †† mean	Upland Soils Softwood Forest †† std err	Upland Soils Softwood Forest †† n
	----------μeq/L----------								
Fe									
Bulk precipitation	-	-	-	-	-	-	-	-	-
Organic horizons	367	89	11	430	140	4	424	177	3
A horizons	91	39	5	151	38	4	70	29	3
Bf1 horizons	13	-	1	35	16	4	22	9	3
Bf2 horizons	11	-	1	39	15	4	13	7	3
Bg horizon	49	24	4	-	-	-	-	-	-
BC horizons	181	-	1	25	8	4	63	52	3
C horizons	-	-	-	24	13	3	18	4	2
Stream Output	37	6	72	22	3	28	60	9	44
Mn									
Bulk precipitation	-	-	-	-	-	-	-	-	-
Organic horizons	71	30	11	281	89	4	100	73	3
A horizons	22	13	5	16	14	4	11	9	3
Bf1 horizons	1.1	-	1	3.6	1.5	4	9.2	6.4	3
Bf2 horizons	0.3	-	1	1.7	0.4	4	3.3	0.5	3
Bg horizon	8.9	4.8	4	-	-	-	-	-	-
BC horizons	3.3	-	1	0.9	0.3	4	5.6	2.5	3
C horizons	-	-	-	1.9	0.6	3	4.1	3.4	2
Stream Output	1.0	0.2	73	1.0	0.2	28	1.1	0.3	45
Al									
Bulk precipitation	-	-	-	-	-	-	-	-	-
Organic horizons	3346	707	11	3296	861	4	2519	794	3
A horizons	2325	727	5	942	186	4	993	360	3
Bf1 horizons	9	-	1	394	183	4	642	536	3
Bf2 horizons	1	-	1	237	70	4	91	7	3
Bg horizon	1691	463	4	-	-	-	-	-	-
BC horizons	3628	-	1	95	34	4	434	380	3
C horizons	-	-	-	8	4	3	68	55	2
Stream Output	16	3	72	20	2	28	12	3	44

† Atkin's Brook, Mount Tom Brook, Pine Marten Brook, and Pebbleloggitch Lake watersheds -- mixedwood

†† Beaverskin Brook, Moosepit Brook, and Roger's Brook watersheds -- predominantly softwoods

* Bulk precipitation was calculated using mean august values measured from CAPMoN station (1979-1989)

** Stream water output (August averages) from grab samples calculated as mean of all watersheds where soil pits were dug, stream water output for mixedwood forest upland soils was averaged between the above mentioned watersheds, and stream water output for softwood forest upland soils was averaged between the above watersheds

nd no data available

K, Na, Cl, Ca, Mg Group

The ion concentrations in this group (K, Na, Cl, Mg) showed the same general trends (Fig. 20; Appendix V E-F; I-L; Q-R). In upland soils, ion concentrations were highest in the forest floor. Within the mineral soil, concentrations tended to increase from the A horizons to the B horizons, and then decreased again towards the BC and C horizons. This type of profile was probably caused by several processes including the fact that high evapotranspirational demands would have increased water losses from the well rooted B layers, thereby increasing the solute concentrations in the mid-soil layers as well.

The main factor contributing to the accumulation of salts in the surface horizons is the ability of a particular layer to retain ions by ion exchange, and ion exchange sites tend to be in equilibrium with ions in solution. Another factor is ion complexation with organic matter. Shaking the soil with water loosens the organic structure somewhat, and some of the complexed ions then appear in the extract.

The pattern was different for the wet spot soils. These soils showed decreasing ion concentrations from the top organic horizons to the mineral soil horizons below (Fig. 20). On many of these spots, tree vegetation was sparse, and root densities were low in the mineral soil below the thick organic surface layers. It is likely that the high surface concentrations were due to seepage coupled with water evaporation from these spots. Seepage would be responsible for the much higher ion concentrations throughout the soil profiles of the wet spots (about 3 times higher than what was found in upland soils). For the upland soils, water-soluble ion concentrations for this group were highest under mixedwood forests (Table 15).

Concentrations for Ca, Mg, Na, Cl, and K in precipitation were consistently lower than Ca, Mg, Na, Cl, and K concentrations in soil solution. Soil solution chemistry, therefore, was not only affected by precipitation inputs, but by within-soil reactions and processes that, in general, lead to ion retention.

Subsoil solution concentrations for Ca and Mg (C horizons) were generally higher than streamwater concentrations for Ca and Mg. A study at the Nashwaak Experimental Watershed Project showed much higher concentrations of Ca in streamwater than in subsoil solutions (Jewett *et al.* 1994). The low subsoil and streamwater Ca concentrations at KNP would be due to a low weathering rate of soil minerals and underlying bedrock formations.

Streamwater concentrations for Na and Cl were nearly identical with the subsoil concentrations for Na and Cl at lowland locations. In contrast, upland subsoil concentrations for Na and Cl were considerably lower than the corresponding streamwater concentrations. This would suggest that Na and Cl ions did not readily enter the generally compacted subsoils of the upland soils, at least not during periods of prolonged drought when upward capillary flow would be the process by which water and ions are transported.

Potassium concentrations were very low in streamwater in comparison to subsoil levels. Other ions which also had relatively low streamwater concentrations were Al and SO_4 (see Table 15). This suggests that ion filtration or retention was not only limited to the soil and the subsoil, but also occurred in the underlying regolith. In general, K retention could be due to K-fixation on silicate mineral surfaces. As well, K, Al and SO_4 could combine to form an Al-K-SO_4 mineral such as alunite (Arp and

Ouimet 1986). Extensive retention of Al in subsoils and possibly beyond the subsoil was noted by Meyer and Arp (1994) for soils similar to those at KNP.

Al, Fe, and Mn group

Water soluble Al, Fe and Mn concentrations showed little variation among the soils. All had a definite trend of decreasing concentrations from the forest floor to the subsoil. Subsoil concentrations were similar to streamwater concentrations (Appendix V G-H; M-N; S-T; Table 15; Fig. 20). Secondary peaks tended to occur for Fe and Mn in the subsoil at the transition between permeable and impermeable soil layers (e.g. between the Bf to BCx and/or the BC to Cx horizons; see Appendix V G-H; M-N; S-T and Fig. 20), or slightly below that transition (e.g., Beaverskin Brook sites). Enhanced concentrations at this interface suggest seepage flow, with portions of the soil acting as a filter. This filtration could be due to cation exchange on soil mineral surfaces (see Chapter 7). Higher concentrations of a specific element on the cation exchange sites also imply higher concentrations of the particular element in the soil solution. On cation exchange sites, retention of Al and Fe would be more effective than retention of bivalent and monovalent cations because of the high affinity between trivalent cations and the negative cation exchange sites. It appears that this particular pattern was most prevalent for wet spots on lowland soils, medium for upland soils under softwoods, and mostly absent in upland soils under mixedwoods.

The general trends seen for Al and Fe repeat themselves with Mn, although the concentrations of Mn tend to be less than that of Fe, and very much less than that of Al. Among the watersheds, water-extractable Mn concentrations were highest in the upland soils of Roger's Brook, thus

suggesting that the mineral composition of the soil parent material in this watershed was somewhat different from the other watersheds (see Appendix V G-H; M-N; S-T).

Concentrations of Al, Fe, and Mn in precipitation were not recorded. Aluminum concentrations were extremely high in subsoil layers of lowlands soils in comparison to streamwater output and to upland subsoils. Upland subsoil Al concentrations were higher than streamwater output under softwood forests, and lower than streamwater under mixedwoods. These differences are likely due to differences in soil pH, with acidic softwood soils generating more mobile Al than the less acidic soils on mixedwood sites.

NO_3 and SO_4 group

On upland soils, higher than average NO_3-N concentrations events occur in the top (forest floor) and middle portions of the soil profiles. Lowest concentrations occurred in Ae layers, and in subsoils towards the C horizons (Fig. 19; Appendix V A-D). Forest floor NO_3-N and SO_4 concentrations were both high at Moosepit Brook, Atkin's Brook, and Mount Tom Brook. This suggests that high nitrification rates occurred in the soils, and that this may have been coupled with a somewhat reduced vegetational NO_3-N uptake from the relatively thin and less well rooted forest floor at these locations. In contrast, NO_3-N concentrations were low at the Roger's Brook and Pine Marten Brook, thereby suggesting limited nitrification in the mainly softwood stands of these watersheds, and also perhaps an efficient rate of NO_3-N uptake from the intensely rooted forest floor (Appendix V A-D). The drought that preceded the sampling effort would have enhanced the upward flux of NO_3-N into the forest floor through capillary flow.

Seepage from the uplands to the lowlands led to increased NO_3-N

concentrations in the top soil portions of the wet spots, and throughout the soils on these wet spots in general. These high concentrations would be due in part to limited root uptake. High NO_3-N concentrations in wet spots, and relatively low NO_3-N concentrations elsewhere, appear to reflect the general post-drought situation. One would expect that some of the NO_3-N so accumulated would be flushed out quickly from each watershed and each wet spot once wet weather returns.

During the summer drought, concentrations of SO_4 were typically highest in the forest floor, and had a secondary peak in the mineral soil at the point where seepage water percolates laterally through the soil on top of a compacted subsoil layer, as already seen for Al and Fe. In these soil layers, an historical build-up of soil-retained SO_4 would be reflected by increased SO_4 concentrations in the soil solution.

Generally, NO_3-N levels were higher in soils than in precipitation, but very little NO_3-N was found in streamwater. Yet, NO_3-N concentrations in lowland soils far exceeded upland NO_3-N concentrations. This suggests that much NO_3-N uptake must occur either within the streams, or within the immediate vicinity of the streams, i.e., wetland-lowland transitions. These transitions offer a strong biotic contrast to uplands and lowlands, and this contrast expresses itself quite clearly by way of vegetational composition, with nitrophilic vegetation (grasses, sedges, reeds) dominating.

CONCLUSION

Post-drought water-soluble ion concentrations in the soils of KNP revealed a pattern that appears to be affected by several processes, namely: (*i*) retention of ions by ion exchange, whereby ion exchange sites tend to be in

equilibrium with ions in solution; (*ii*) ion complexation with organic matter; (*iii*) root uptake, which reduces nutrient ion concentrations in heavily rooted layers (especially NO_3-N); (*iv*) seepage, that leads to an even greater build-up of water-soluble ions at locations that remain moist and wet throughout the drought period; (*v*) soil filtration of ions, particularly of highly charged ions, at the non-compacted - compacted soil-subsoil interface, and; (*vi*) the pattern of soil compaction.

Vegetation type appears to affect soil water quality: soil water under mixedwoods tends to contain high levels of ions, especially Ca, Mg, K; retention of ions increases with increasing soil depth (mixedwood sites have subsoil water with lower mineral content than softwood sites); mixedwood sites have more base cations in the subsoil solution than softwood sites; softwood sites have more water-soluble Al in subsoil water than mixedwood sites.

August streamwater concentrations were all lower than subsoil water concentrations for most ions, except Na and Cl. The latter tended to be high in topsoils and within seepage water at this time of year.

CHAPTER 7

EXCHANGEABLE CATIONS IN KEJIMKUJIK NATIONAL PARK SOILS

INTRODUCTION

The preceding chapter has dealt with the analysis of post-drought ion composition of the soil solution at KNP. In this chapter, attention is given to the ion composition of the cation exchange complex of the various soils that were investigated. For cations (Ca, Mg, K, Mn, Fe, Al), exchangeable ions include the largest pool of ions that are available for plant uptake (e.g., Ca, Mg, K, NH_4), and, more generally, are subject to ion mobilization on account of ion exchange reactions. Such mobilization is based on the law of mass action, i.e., the equilibrium formulation that describes the balance between ions in solution and ions on the ion exchange surface (Bohn *et al.* 1985). The latter can, in part, be addressed by examining the ratio of ions in solution to ions on the exchange sites.

This chapter serves to document the ion composition on the cation exchange sites, and to explore how this composition varies between each soil and within each soil, according to the landscape in which the soil is located (upland hardwoods, upland softwoods, lowlands). This chapter will also explore soil depth and specific soil profile features. The pattern established in the preceding chapter will be followed in this chapter. In addition, this chapter will also determine the proportion of ions in solution (Chapter 6) to

ions on exchange sites.

Throughout the chapter, the assumption is made that: *exchangeable ion concentrations = neutral 1 N NH_4Cl concentrations* (Meyer *et al.* 1994). This assumption is required because exchangeable ion concentrations cannot be determined directly, but only through a process that displaces the surface retained ions into solution. The process involves adding a strong salt solution to the soil that was sampled for analysis purposes. In fact, the cations of the salt solution (in this case NH_4) exchange with all the other ions that may be found on the soil surfaces, including NH_4.

Among all the ions so displaced, Si plays a special role. Technically, Si is likely not in ion form, but occurs on the exchange sites as a neutral $Si(OH)_4$ species. Following extraction with NH_4Cl, some Si is also found in the resulting solutions. The quantities so extracted are also reported here, and may serve as an index for the general weatherability of the soil.

Summing the charge equivalents of all the 1N NH_4Cl-extracted ions allows one to estimate the cation exchange capacity of the soils so examined. In general, the cation exchange capacity is important for assessing the ability of the soils to retain cations, and nutrient cations in particular.

METHODS

The soil samples used for determining the chemical composition of the soil solutions in Chapter 6 were used to determine exchangeable cation contents. The field study methods are explained in Chapter 6. Laboratory analysis involved the following protocol: (*i*) extract the soils with deionized water to determine water-soluble ion concentrations, (5 g of moist soil in 10 ml of extract, 2.5 g of moist organic soil in 15 ml of extract, see preceding chapter); (*ii*) extract the same soil once again, but this time with an 1N

NH_4Cl solution (i.e., same amount of soil, 10 ml of neutral salt solution). The extract then is used to determine the 1 N NH_4Cl-extractable concentrations of Ca, Mg, K, Mn, Na, Fe, Al, and Si, by means of atomic absorption spectrophotometry (McKeague 1978).

Comparisons were made between water-soluble ion concentrations in soil versus exchangeable ion concentrations in soil in order to quantify the ratio between the two. This ratio was calculated as follows:

$$\frac{\text{Water-Soluble ion concentrations (meq/100g moist soil)}}{\text{1N } NH_4Cl\text{-extractable ion concentrations (meq/100g moist soil).}}$$

The cation exchange capacity (CEC) of each soil sample was obtained from the following formula:

CEC (meq/100g) = sum of 1N NH_4Cl extractable Ca, Mg, K, Na, Al, Fe, Mn (meq/100g of moist soil)

(1 for K and Na; 2 for Mg, Ca and Mn, 3 for Al and Fe).

RESULTS AND DISCUSSION

Exchangeable Cation Concentrations

Table 16 lists average 1N NH_4Cl extractable cation concentrations for each horizon for lowland and upland soils; cation exchange capacities are also listed.

Table 16. Means, standard errors, and numbers of samples for exchangeable ion concentrations (K, Ca, Mg, Na, Fe, Mn, Al, Si) in soil measured in KNP

Stratum	Lowland Soils			Upland Soils Mixedwood Forest †			Upland Soils Softwood Forest ††		
	mean	*std err*	*n*	*mean*	*std err*	*n*	*mean*	*std err*	*n*
	meq/100g								
	Cation Exchange Capacity (-)								
Organic horizons	11.754	1.518	11	9.370	0.675	4	5.670	1.240	3
A horizons	5.603	1.363	5	3.358	0.667	4	4.374	1.412	3
Bf1 horizons	0.996	-	1	1.038	0.272	4	2.324	1.200	3
Bf2 horizons	0.674	-	1	0.680	0.205	4	0.673	0.109	3
Bg horizon	2.847	0.633	4	-	-	-	-	-	-
BC horizons	2.107	-	1	0.850	0.291	4	0.468	0.101	3
C horizons				0.590	0.189	3	0.443	0.086	2
	K (+)								
Organic horizons	0.513	0.101	11	0.985	0.106	4	0.417	0.026	3
A horizons	0.129	0.028	5	0.090	0.015	4	0.070	0.016	3
Bf1 horizons	0.077	-	1	0.102	0.026	4	0.071	0.018	3
Bf2 horizons	0.083	-	1	0.056	0.012	4	0.045	0.006	3
Bg horizon	0.102	0.027	4	-	-	-	-	-	-
BC horizons	0.131	-	1	0.051	0.014	4	0.050	0.015	3
C horizons				0.045	0.021	3	0.050	0.026	2
	Ca (2+)								
Organic horizons	3.422	0.953	11	4.188	0.357	4	1.764	0.782	3
A horizons	0.902	0.419	5	0.115	0.039	4	0.157	0.079	3
Bf1 horizons	0.007	-	1	0.079	0.029	4	0.039	0.020	3
Bf2 horizons	0.014	-	1	0.044	0.023	4	0.010	0.004	3
Bg horizon	0.286	0.095	4	-	-	-	-	-	-
BC horizons	0.029	-	1	0.039	0.018	4	0.014	0.003	3
C horizons				0.041	0.025	3	0.026	0.005	2
	Mg (2+)								
Organic horizons	1.758	0.557	11	1.590	0.073	4	0.575	0.243	3
A horizons	0.270	0.089	5	0.118	0.034	4	0.079	0.032	3
Bf1 horizons	0.030	-	1	0.057	0.009	4	0.045	0.014	3
Bf2 horizons	0.034	-	1	0.040	0.011	4	0.027	0.011	3
Bg horizon	0.232	0.066	4	-	-	-	-	-	-
BC horizons	0.128	-	1	0.038	0.010	4	0.032	0.018	3
C horizons				0.046	0.017	3	0.050	0.038	2
	Na (+)								
Organic horizons	0.321	0.030	11	0.070	0.024	4	0.111	0.046	3
A horizons	0.100	0.027	5	0.005	0.001	4	0.014	0.003	3
Bf1 horizons	0.011	-	1	0.011	0.006	4	0.006	0.002	3
Bf2 horizons	0.012	-	1	0.005	0.002	4	0.007	0.002	3
Bg horizon	0.050	0.002	4	-	-	-	-	-	-
BC horizons	0.048	-	1	0.008	0.005	4	0.007	0.001	3
C horizons				0.004	0.002	3	0.003	0.001	2

Table 16. (Continued)

Stratum	Lowland Soils mean	Lowland Soils std err	Lowland Soils n	Upland Soils Mixedwood Forest † mean	Upland Soils Mixedwood Forest † std err	Upland Soils Mixedwood Forest † n	Upland Soils Softwood Forest †† mean	Upland Soils Softwood Forest †† std err	Upland Soils Softwood Forest †† n
	meq/100g								
Fe (3+)									
Organic horizons	0.269	0.051	11	0.604	0.220	4	0.266	0.131	3
A horizons	0.070	0.027	5	0.038	0.020	4	0.032	0.017	3
Bf1 horizons	0.003	-	1	0.007	0.002	4	0.011	0.001	3
Bf2 horizons	0.002	-	1	0.009	0.006	4	0.006	0.002	3
Bg horizon	0.047	0.017	4	-	-	-	-	-	-
BC horizons	0.062	-	1	0.005	0.001	4	0.025	0.012	3
C horizons				0.005	0.002	3	0.018	0.016	2
Mn (2+)									
Organic horizons	0.173	0.094	11	0.295	0.061	4	0.225	0.137	3
A horizons	0.123	0.106	5	0.023	0.020	4	0.033	0.030	3
Bf1 horizons	0.004	-	1	0.010	0.004	4	0.024	0.019	3
Bf2 horizons	0.004	-	1	0.005	0.002	4	0.008	0.003	3
Bg horizon	0.043	0.036	4	-	-	-	-	-	-
BC horizons	0.004	-	1	0.005	0.003	4	0.007	0.004	3
C horizons				0.002	0.000	3	0.009	0.008	2
Al (3+)									
Organic horizons	4.696	0.873	11	0.992	0.307	4	2.093	0.183	3
A horizons	3.786	1.140	5	2.786	0.587	4	3.861	1.424	3
Bf1 horizons	0.760	-	1	0.608	0.231	4	1.956	1.279	3
Bf2 horizons	0.401	-	1	0.338	0.138	4	0.366	0.112	3
Bg horizon	1.906	0.746	4	-	-	-	-	-	-
BC horizons	1.569	-	1	0.505	0.236	4	0.176	0.068	3
C horizons				0.212	0.162	3	0.130	0.014	2
Si (mole/100g)									
Organic horizons	0.602	0.106	11	0.647	0.203	3	0.220	0.098	3
A horizons	0.223	0.091	5	0.183	0.041	4	0.127	0.023	3
Bf1 horizons	0.104	-	1	0.165	0.024	4	0.171	0.091	3
Bf2 horizons	0.125	-	1	0.183	0.052	4	0.203	0.104	3
Bg horizon	0.181	0.050	4	-	-	-	-	-	-
BC horizons	0.136	-	1	0.199	0.050	4	0.157	0.012	3
C horizons				0.235	0.055	3	0.157	0.031	2

† Atkin's Brook, Mount Tom Brook, Pine Marten Brook, and Pebbleloggitch Lake watersheds -- mixedwood

†† Beaverskin Brook, Moosepit Brook, and Roger's Brook watersheds -- predominantly softwoods

nd no data available

Cation exchange capacities were generally higher in lowland soils than upland soils. This is caused by the higher organic matter contents of the lowland soils (see Chapter 9). The cation exchange capacities of the soils at KNP were low in comparison with cation exchange capacities of the soils in other regions, such as New Brunswick and Ontario (Meyer *et al.* 1994). The cation exchange capacities for the organic forest floor layers were particularly low. The cause for this was the high acidity of these layers, with most layers having a pH of about 3 (Meyer *et al.* 1994). Such low cation exchange capacities indicate that the overall ability of soils to retain cations was relatively low at KNP, thereby making these soils vulnerable to a general depletion of the already low nutrient pools within the soils.

In terms of displaying and discussing results obtained with the 1N NH_4Cl-extractable ion concentrations, upland soils are grouped as in Chapter 6, i.e.: lowland soils, soils under mixedwood cover types, and soils under softwood cover types. General trends are graphically displayed in Figure 21. Each watershed is displayed separately in Appendix VI (A to R).

The following trends were found for the 1 N NH_4Cl-extractable cations: (*i*) there were high concentrations in the surface organic horizons, and low concentrations beneath B horizons; (*ii*) differences between upland and lowland soils were relatively smaller than the corresponding differences for water-soluble ions, and; (*iii*) thick organic horizons showed particularly high concentrations for Ca, Mg, and Al.

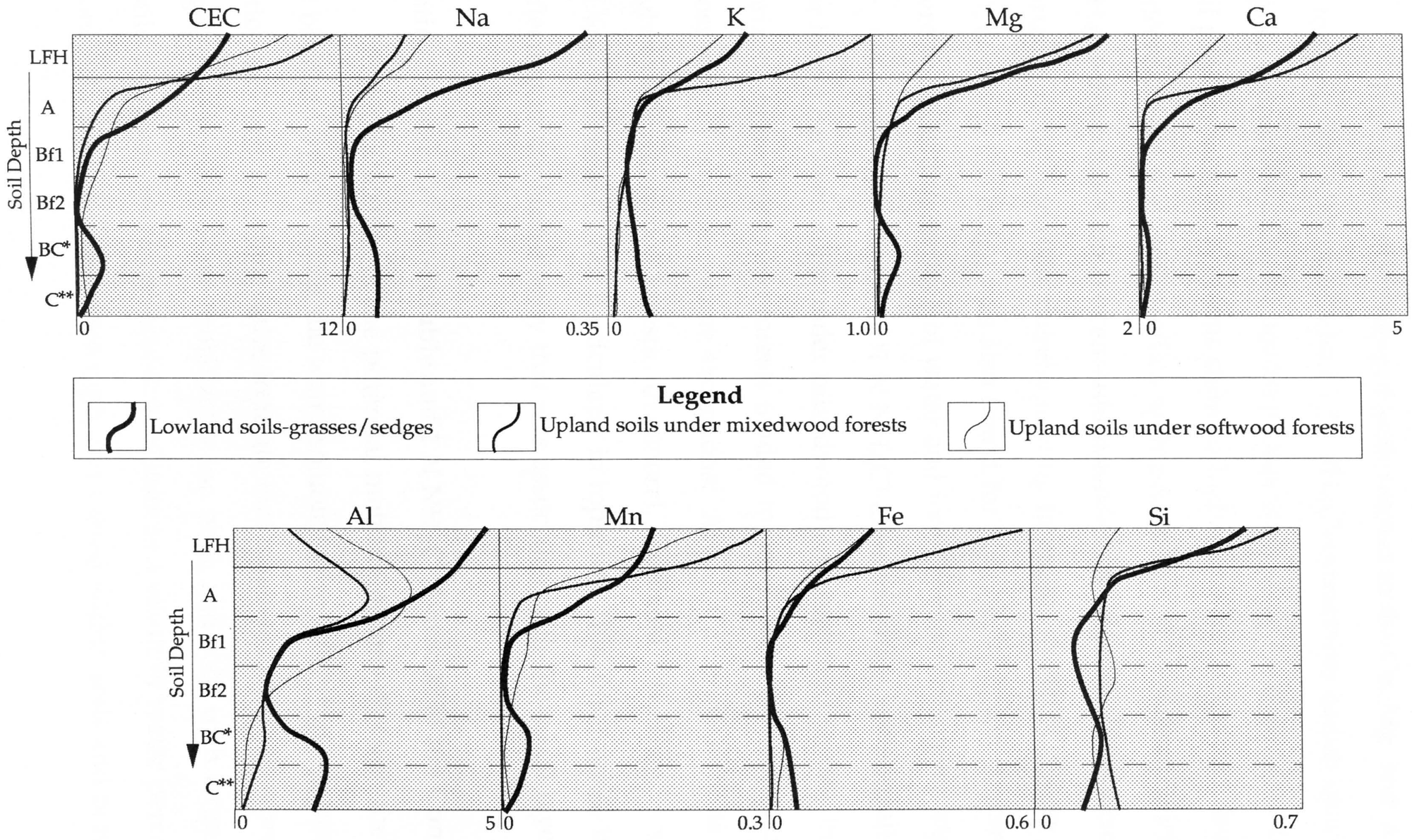


Fig. 21. General soil profile trends found for exchangeable cation concentrations (meq/100g). Note: * BC horizons represent Bg horizons for lowland soils; ** C horizons reprepsent BC horizons for lowland soils.

The pattern that emerged with respect to the Ca, Mg, and Al ions was as follows: (*i*) "A" horizons had 1 N NH_4Cl-extractable cation concentrations higher than other mineral horizons (this was particularly the case for Al); (*ii*) soil profiles with Bg horizons showed higher 1 N NH_4Cl-extractable cation concentrations than soil profiles with podzolised Bf horizons; (*iii*) 1 N NH_4Cl-extractable ion concentrations tended to increase slightly from Bf horizons to BC horizons, thereby leading to bulges in the BC layers (Figure 21), and; (*iv*) this bulge was also found for water-soluble ion concentrations, thereby indicating seepage of water and ions over the compacted subsoils.

Large differences for 1 N NH_4Cl-extractable ion concentrations were not found between soils under mixedwood and softwood forests, but A horizons under softwood forests tended to have lower concentrations for most ions. There were some exceptions: Al and Ca concentrations were both higher under softwood forests. In general, estimated 1 N NH_4Cl-extractable Al was high overall, but particularly in topsoils. This, once again, is a direct reflection of the high acidity that was associated with these soil layers.

Ratios Between Water-Soluble and 1 N NH_4Cl-Extractable Ion Concentrations

An indication of the potential mobility of ions through the soils can be obtained by inspecting the water-soluble ion to 1 N NH_4Cl-extractable ion ratios in Table 17. High ratios indicate that water-soluble ions represent a significant portion of the mobilizable ion pool, and soils with large ratios could therefore lose large amounts of ions as a result of water percolation alone. As shown, ratios were high, but varied within soils and between soils.

Table 17. Means, standard errors, and numbers of samples for water-soluble and exchangeable ion concentration ratios (K, Ca, Mg, Na, Fe, Mn, Al)

	Lowland Soils			Upland Soils Mixedwood Forest †			Upland Soils Softwood Forest ††			Overall Averages for Forest Floor and Mineral Soil		
Stratum	*mean*	*std err*	*n*	*mean*	*std err*	*n*	*mean*	*std err*	*n*	*mean*	*std err*	*Total n*
					K (+)					*In Forest Floor:*		
Organic horizons	0.52	0.10	11	0.33	0.04	4	0.25	0.03	3	0.37	0.08	18
A horizons	0.17	0.03	5	0.16	0.03	4	0.12	0.02	3			
Bf1 horizons	0.11	0.11	1	0.12	0.03	4	0.12	0.03	3			
Bf2 horizons	0.08	0.08	1	0.08	0.02	4	0.08	0.02	3			
Bg horizon	0.17	0.07	4	-	-	-	-	-	-			
BC horizons	0.17	0.17	1	0.11	0.03	4	0.15	0.10	3			
C horizons	-	-	-	0.19	0.12	3	0.14	0.09	2			
In Mineral Soil:	Overall means		Total n	Overall means		Total n	Overall means		Total n	*In Mineral Soil:*		
	0.14	0.02	12	0.13	0.02	19	0.12	0.01	14	0.13	0.01	45
					Ca (2+)					*In Forest Floor:*		
Organic horizons	*0.92*	*0.36*	*5*	0.50	0.34	4	0.76	0.17	3	0.73	0.12	12
A horizons	*0.56*	*0.23*	*4*	0.13	0.03	4	0.09	0.04	3			
Bf1 horizons	0.53	-	1	0.20	0.04	4	1.05	0.78	3			
Bf2 horizons	0.59	-	1	0.46	0.17	4	0.72	0.13	3			
Bg horizon	*0.34*	*0.29*	*3*	-	-	-	-	-	-			
BC horizons	0.24	-	1	0.29	0.12	4	0.61	0.27	3			
C horizons	-	-	-	0.37	0.16	3	0.23	0.00	2			
In Mineral Soil:	Overall means		Total n	Overall means		Total n	Overall means		Total n	*In Mineral Soil:*		
	0.45	0.07	10	0.29	0.06	19	0.54	0.17	14	0.43	0.07	43
					Mg (2+)					*In Forest Floor:*		
Organic horizons	*1.86*	*0.60*	*5*	0.90	0.67	4	0.72	0.35	3	1.16	0.35	12
A horizons	*1.30*	*0.71*	*4*	0.09	0.01	4	0.08	0.03	3			
Bf1 horizons	0.35	-	1	0.24	0.03	4	0.37	0.11	3			
Bf2 horizons	0.22	-	1	0.31	0.08	4	0.41	0.08	3			
Bg horizon	*0.44*	*0.38*	*3*	-	-	-	-	-	-			
BC horizons	0.09	-	1	0.16	0.05	4	0.33	0.03	3			
C horizons	-	-	-	0.17	0.07	3	0.22	0.07	2			
In Mineral Soil:	Overall means		Total n	Overall means		Total n	Overall means		Total n	*In Mineral Soil:*		
	0.48	0.21	10	0.19	0.04	19	0.28	0.06	14	0.32	0.08	43
					Na (+)					*In Forest Floor:*		
Organic horizons	0.56	0.11	11	4.61	2.22	4	3.56	2.40	3	2.91	1.21	18
A horizons	0.30	0.01	5	1.76	0.31	4	0.79	0.19	3			
Bf1 horizons	0.44	0.44	1	1.94	0.66	4	10.10	5.57	3			
Bf2 horizons	0.50	0.50	1	6.54	3.24	4	1.06	0.12	3			
Bg horizon	0.28	0.06	4	-	-	-	-	-	-			
BC horizons	0.21	0.21	1	1.78	0.66	4	0.72	0.14	3			
C horizons	-	-	-	1.98	0.52	3	1.45	0.58	2			
In Mineral Soil:	Overall means		Total n	Overall means		Total n	Overall means		Total n	*In Mineral Soil:*		
	0.35	0.05	12	2.80	0.94	19	2.82	1.82	14	1.99	0.82	45

Table 17. (Continued)

Stratum	Lowland Soils mean	Lowland Soils std err	Lowland Soils n	Upland Soils Mixedwood Forest † mean	Upland Soils Mixedwood Forest † std err	Upland Soils Mixedwood Forest † n	Upland Soils Softwood Forest †† mean	Upland Soils Softwood Forest †† std err	Upland Soils Softwood Forest †† n	Overall Averages for Forest Floor and Mineral Soil mean	std err	Total n
					Fe (3+)					*In Forest Floor:*		
Organic horizons	0.20	0.05	11	0.10	0.03	4	0.42	0.20	3	0.24	0.09	18
A horizons	0.56	0.37	5	0.73	0.25	4	0.33	0.11	3			
Bf1 horizons	0.36	0.36	1	0.44	0.11	4	0.18	0.08	3			
Bf2 horizons	0.54	0.54	1	1.88	0.84	4	0.37	0.22	3			
Bg horizon	0.53	0.37	4	-	-	-	-	-	-			
BC horizons	0.29	0.29	1	1.84	1.28	4	1.43	1.37	3			
C horizons	-	-	-	0.61	0.26	3	0.52	0.47	2			
In Mineral Soil:	Overall means		Total n	Overall means		Total n	Overall means		Total n	*In Mineral Soil:*		
	0.46	0.05	12	1.10	0.31	19	0.57	0.22	14	0.71	0.20	45
					Mn (2+)					*In Forest Floor:*		
Organic horizons	0.41	0.22	11	0.08	0.01	4	0.03	0.01	3	0.17	0.12	18
A horizons	0.07	0.03	5	0.09	0.02	4	0.07	0.03	3			
Bf1 horizons	0.03	0.03	1	0.07	0.03	4	0.03	0.01	3			
Bf2 horizons	0.01	0.01	1	0.14	0.07	4	0.06	0.02	3			
Bg horizon	0.17	0.12	4	-	-	-	-	-	-			
BC horizons	0.09	0.09	1	0.05	0.02	4	0.17	0.10	3			
C horizons	-	-	-	0.28	0.14	3	0.11	0.04	2			
In Mineral Soil:	Overall means		Total n	Overall means		Total n	Overall means		Total n	*In Mineral Soil:*		
	0.07	0.03	12	0.13	0.04	19	0.09	0.02	14	0.10	0.02	45
					Al (3+)					*In Forest Floor:*		
Organic horizons	*0.61*	*0.30*	*5*	0.42	0.10	4	0.13	0.05	3	0.39	0.14	12
A horizons	*0.96*	*0.81*	*4*	0.03	0.00	4	0.04	0.02	3			
Bf1 horizons	0.00	-	1	0.12	0.06	4	0.05	0.03	3			
Bf2 horizons	0.00	-	1	1.03	0.91	4	0.03	0.01	3			
Bg horizon	*0.21*	*0.15*	*3*	-	-	-	-	-	-			
BC horizons	0.27	-	1	0.56	0.53	4	0.49	0.45	3			
C horizons	-	-	-	0.02	0.02	3	0.06	0.05	2			
In Mineral Soil:	Overall means		Total n	Overall means		Total n	Overall means		Total n	*In Mineral Soil:*		
	0.29	0.18	10	0.35	0.20	19	0.13	0.09	14	0.26	0.06	43

† Atkin's Brook, Mount Tom Brook, Pine Marten Brook, and Pebbleloggitch Lake watersheds
-- mixedwood
†† Beaverskin Brook, Moosepit Brook, and Roger's Brook watersheds -- predominantly softwoods
Numbers in italics exclude Mount Tom Brook, Pebbleloggitch Lake,
and Beaverskin Brook watersheds from calculation

Highest ratios were found in soils with high organic matter contents, especially for soil samples taken from the forest floor, i.e. Ah layers and Bf layers. This is not surprising because soils with large organic matter pools tend to have large amounts of water-displaced organic matter as well. Displacement of organic matter, as it occurs when the soils are extracted with deionized water, would carry with it corresponding amounts of organically held cations. No attempts were made in the soil extraction procedure to filter the organic matter displaced from the soil extracts (see preceding chapter). An attempt to do so would have likely reduced the ratios in Table 17 towards those ratios that are found for the soil layers with low organic matter content.

While extraction with deionized water tended to produce coloured extracts, extractions with 1 N NH_4Cl solutions produced clear and generally colour-free solutions. This would be due to two reasons: (*i*) 1 N NH_4Cl solutions follow the preceding deionized water extraction from the same soil samples, hence a considerable portion of the water-soluble amount of organic matter was already removed before adding the 1 N NH_4Cl solution; (*ii*) high salt concentrations help to coagulate soil organic matter and other soil colloids, and this occurs by a substantial decrease of the repulsive forces that exist between individual soil particles at low to zero salt concentrations ("salting-out" effect, see Bohn *et al.* 1985).

The ratios in Table 17 were generally not significantly different when compared by soil type. Ratios, however, differed by ion type, according to the following sequence for the forest floor:

$$Mn < Fe < K \approx Al << Ca < Mg << Na;$$

and for the mineral soil:

$$Mn < K << Al < Mg < Ca << Fe << Na.$$

The low water-solubility ratios of both Mn and K in relation to exchangeable Mn and K in the forest floor and in the mineral soil are somewhat surprising in comparison with the relatively high ratios of the other ions listed in Table 17. One could have expected that Mn would be strongly complexed by organic matter, thereby enhancing the water solubility for this element as this appears to be the case for Fe, Al, Ca Mg and Ca. It appears, however, that Mn, once on the exchange sites, remains exchangeable for the most part, and very little of it enters the solution as an organic complex. Potassium, unlike the bivalent or trivalent ions, is likely not complexed with organic matter. The low degree of water hydration of this ion, however, allows for a high affinity with ion exchange sites due to the proximity of positive and negative charge centres. In contrast, Na has a high degree of ionic hydration, and therefore forms electrostatic bonds with the exchange sites (Bohn *et al.* 1985). Consequently, this ion remains in solution for the most part.

The high ratio for Fe in the mineral soils likely has a cause opposite to that of Na: surface sorbed Fe would likely form strong bonds with Fe oxide/hydroxide minerals, thereby keeping the amount of exchangeable Fe low, hence rendering the ratio of water-soluble Fe to exchangeable Fe high.

With respect to Ca and Mg, mobility appears to be much higher in the forest floor than in the mineral soil. High mobility in the forest floor is likely due to complexation with organic matter, with one part of Ca and Mg becoming mobile, and the other part not, depending on whether the organic matter itself is mobile or not. The ratio for Al also appears to be somewhat higher in the forest floor, and somewhat lower in the mineral soil, possibly due to a partial transformation of its exchangeable form to an

oxide/hydroxide form. This transformation would be analogous to that of Fe, although not as extensive on account of the higher solubility of Al oxide/hydroxide minerals at the prevailing pH conditions from about 3 to about 6.

CONCLUSIONS

Exchangeable cations in the soils of KNP revealed a pattern of high ion concentrations in the surface organic and in surface mineral horizons, and low levels in the subsoil horizons. There were two other distinct patterns: (*i*) the differences between upland and lowland soils were not as strong as was found for water-soluble ion concentrations; (*ii*) there were no pronounced differences between 1 N NH_4Cl-extractable cations under mixedwoods and softwoods, except that 1 N NH_4Cl-extractable Ca, K, and Mg were usually lower under softwoods (more acidic conditions) than mixedwoods.

The overall impressions gained from the water-soluble to exchangeable ion ratios as listed in this chapter are: (*i*) Na is the most mobile element in both the forest floor and the mineral soil, with little extra Na to be found on the ion exchange sites; (*ii*) Ca and Mg are also fairly mobile in both soil layer types, with a considerable portion of the available Ca and Mg present in the soil solution; (*iii*) water solubilities of K, Mn, and Al are low in comparison with the amounts of K, Mn, and Al that can be found on the cation exchange sites, and; (*iv*) a high proportion of Fe that is available tends to be in the soil solution of the mineral soil.

CHAPTER 8

TOTAL WATER-SOLUBLE AND EXCHANGEABLE IONS IN SOIL: RELATIONSHIPS TO STREAMWATER

INTRODUCTION

The chemical composition of the soil solution and of the cation exchange complex at KNP was addressed in the preceding two chapters with respect to changes within soil profiles by soil type, i.e., upland mixedwoods, upland softwoods, and lowlands. This chapter addresses the chemical composition of the soil solution and the cation exchange complex soil at the watershed level on a per hectare basis. This is done by converting ion concentrations per soil layers into total amounts of water-soluble and exchangeable ions (i.e. 1 N NH_4Cl-extractable ions) per soil type. In turn, the proportions of soil types per watershed are used to generate total amounts of water-soluble and exchangeable ions for a given watershed. The watersheds are then grouped into those which are mainly covered by mixedwood forests (Atkins Brook, Mount Tom Brook, Pine Marten Brook, Pebbleloggitch Lake), and those that are mainly covered by softwoods (Beaverskin Brook, Moosepit Brook, Roger's Brook). The quantities of ions so evaluated are then compared with the annual ion loads of the primary streams specific to each watershed. This comparison was done in order to estimate the turn-over time required for flushing current water-soluble and exchangeable ion pools from each watershed on the assumption that further inputs would cease, and

that stream ion loads would continue at current annual level. These turnover times are calculated as follows:

$$\text{Turnover time for water-soluble ions (years)} = \frac{\text{Total water-soluble ion concentrations (eq/ha)}}{\text{Streamwater ion fluxes (eq/ha/year)}}$$

and

$$\text{Turnover time for exchangeable ions (years)} = \frac{\text{1 N } NH_4Cl \text{ extractable cations (eq/ha)}}{\text{Streamwater ion fluxes (eq/ha/year)}}.$$

METHODS

Total water-soluble ion and exchangeable (1 N NH_4Cl-extractable) cation concentrations (eq/ha) in soil rooting horizons were estimated for each soil based on ion concentrations (Table 15 and 16), depth of rooted soil layers (h), bulk density of soil layers (Db), and proportion of wetlands versus uplands (Tables 18, 19 and 20). Estimated totals were calculated for August only. The equation utilized is as follows:

$$\text{Total per soil (eq/ha)} = \text{ion concentration [meq/100g]} * Db\ [g/cm^3] * h\ [cm] * [10^8 cm^2/ha] * [10^{-3}\ eq/meq]$$

Soil bulk density was assumed to be 1.2 g/cm^3 for all mineral soil horizons, and 0.1 g/cm^3 for all organic horizons. Soil depths were measured during the field study, and were used for all calculations (Appendix IV).

For each watershed, eq/ha totals were calculated for each of the two upland soil profiles, and these were then averaged to provide one total. The

same process was done for the lowland soils. Watershed water-soluble ion and exchangeable cation totals (eq/ha) were weight-averaged based on the known wetland (lowland) percentage within each watershed. Turnover times were obtained from the resulting watershed totals (as they existed for August, 1993), and by dividing these totals with the average annual ion loads of each stream specific to a particular watershed.

RESULTS AND DISCUSSION

Total water-soluble and exchangeable ion concentrations are presented in Tables 18, 19 and 20. As shown in Table 18, total eq/ha ion concentrations were generally larger for mixedwood forests than softwood forests. This is in part due to deeper rooting, and also in part due to higher nutrient ion concentrations of mixedwood soils. Lowlands tended to have the same or larger ion pools than either upland soil type, in spite of severely restricted rooting resulting from high water tables and/or poor soil drainage.

Relatively large lowland ion pools were registered for water-soluble NO_3-N, Ca, Mg, and Al, and this was evident more for some lowland soils than for others, as indicated in Table 18, by including or excluding certain soils from the average and standard error calculations. This, in turn, suggests that lowlands tend to be more variable in terms of their water-soluble nutrient and Al loads than either of the two upland soil types. Causes for this variability likely relate to topography, with lowlands being the recipient of variable amounts of seepage water and associated ion loads. These variations also express themselves in greater lowland diversity than upland diversity: lowlands range from nutrient poor bogs (mainly ericaceous vegetation) to nutrient rich fens and marshes (sedge and reed vegetation dominant).

Table 18. Total water-soluble and exchangeable ion concentrations (eq/ha) in soil rooting horizons

	Total Water-Soluble Ion Concentrations (eq/ha)																					
	Cl		NO3		SO4		Fe		K		Na		Mn		Ca		Mg		Al		H+	
Uplands-Mixedwoods	**950**	58	**109**	8	**3119**	376	**248**	14	**456**	14	**614**	39	**24**	1	**864**	28	**630**	17	**1689**	101	**4.10**	0.23
					1475†	64†																
Uplands-Softwoods	**686**	71	**120**	14	**1093**	118	**112**	7	**301**	15	**636**	47	**30**	2	**530**	43	**508**	48	**1836**	231	**5.48**	0.50
Lowland Soils	**742**	70	**344**	58	**1642**	234	**140**	11	**455**	33	**594**	75	**17**	1	**6318**	1756	**4607**	1008	**15221**	3941	**3.58**	0.37
															1120*	122*	**829***	78*	**4305***	617*		

	Average	Total Exchangeable Ion Concentrations (eq/ha)															
	Soil Depth (cm)	Si		Fe		K		Na		Mn		Ca		Mg		Al		CEC	
Uplands-Mixedwoods	50	**8316**	429	**666**	38	**3820**	136	**350**	25	**464**	20	**4516**	183	**2948**	83	**30400**	1600	**51500**	2000
Uplands-Softwoods	41	**7037**	482	**480**	18	**2439**	121	**388**	25	**822**	76	**2306**	205	**1777**	96	**57100**	5800	**72400**	6000
Lowland Soils	28	**3520**	626	**985**	109	**1754**	121	**1768**	304	**498**	88	**9517**	923	**6015**	620	**47600**	5900	**72000**	7500

Bold numbers represent averages, other numbers represent standard errors
† averages excluding Mount Tom Brook and Pebbleloggitch Lake
*averages excluding Mount Tom Brook, Pebbleloggitch Lake and Beaverskin Brook

Table 19. Total water-soluble ions (eq/ha) in upland and lowland† soil rooting horizons

Watershed ††	% Wetlands	Dominant Vegetation	Cl	NO3	SO4	Fe	H+	K	Na	Mn	Ca	Mg	Al	Ion Balance ∑ Anions	∑ Cations	Δ
MIXEDWOOD FORESTS																
Atkin's Brook	4.5	Treed Bogs, Shrub Swamps, Meadow	929	61	1533	383	4	496	788	17	692	705	2005	2523	5088	2565
Mount Tom Brook	1.3	Shrub Swamps, Treed Bog	1764	202	7037	326	3	635	867	31	1319	1005	3624	9003	7810	-1192
Pine Marten Brook	7.5	Open Bog	426	128	1335	96	2	422	525	37	1113	686	992	1889	3874	1985
Pebbleloggitch Lake	16.5	Treed Bog	692	106	2389	170	7	276	319	11	1018	903	2960	3186	5664	2477
		Mixedwood Averages	**953**	**124**	**3073**	**244**	**4**	**457**	**625**	**24**	**1035**	**825**	**2395**	**4150**	**5609**	**1459**
		Standard error	289	29	1341	67	1	75	125	6	131	78	574	1639	823	893
SOFTWOOD FORESTS																
Beaverskin Brook	<1	Treed Bogs, Meadow, Shrub Swamp	488	-	591	92	11	356	756	8	371	285	941	1079	2820	1742
Moosepit Brook	0.5	Treed and Open Bog	485	129	561	103	3	155	295	16	301	389	2968	1175	4231	3056
Roger's Brook	0.6	Shrub Swamp, Treed Bog	1078	232	2118	139	2	390	849	65	980	890	1692	3427	5006	1579
		Softwood Averages	**683**	**180**	**1090**	**111**	**5**	**300**	**633**	**30**	**550**	**521**	**1867**	**1894**	**4019**	**2126**
		Standard error	197	42	514	14	3	73	171	18	216	187	591	767	640	467

† bulk densities were assumed to be equal to 0.1 g/cm3 for organic horizons, and 1.2 g/cm3 for mineral soil

†† watershed calculations were based on setting % wetlands as lowland soils; and remaining % watershed area for upland soils (Table 4; Appendix VIII)

Table 20. Total exchangeable cations (eq/ha) in upland and lowland† soil rooting horizons

Watershed ††	% Wetlands	Dominant Vegetation	Ca	Mg	K	Mn	Na	Fe	Al	Si	CEC
MIXEDWOOD FORESTS											
Atkin's Brook	4.5	Treed Bogs, Shrub Swamps, Meadow	3245	3305	5088	482	586	925	49708	12654	75994
Mount Tom Brook	1.3	Shrub Swamps, Treed Bog	3100	2621	3920	327	212	536	32455	6363	49534
Pine Marten Brook	7.5	Open Bog	7804	3995	4158	911	600	904	24039	7423	49834
Pebbleloggitch Lake	16.5	Treed Bog	3429	2969	1691	87	366	350	21386	5362	35638
		Mixedwood Averages	**4394**	**3223**	**3714**	**452**	**440.96**	**679**	**31897**	**7950**	**52750**
		Standard error	1139	293	720	173	93.19	142	6389	1623	8426
SOFTWOOD FORESTS											
Beaverskin Brook	<1	Treed Bogs, Meadow, Shrub Swamp	722	781	2441	112	301	523	41200	12128	58208
Moosepit Brook	0.5	Treed and Open Bog	2011	2286	1620	371	260	507	92254	3078	102387
Roger's Brook	0.6	Shrub Swamp, Treed Bog	4376	2349	3217	1981	609	408	37072	5747	55759
		Softwood Averages	**2370**	**1805**	**2426**	**821**	**390.06**	**479**	**56842**	**6984**	**72118**
		Standard error	1070	513	461	585	109.98	36	17746	2685	15151

CEC = cation exchange capacity

† bulk densities were assumed to be equal to 0.1 g/cm3 for organic horizons, and 1.2 g/cm3 for mineral soil

†† watershed calculations were based on setting % wetlands as lowland soils; and remaining % watershed area for upland soils (Table 4; Appendix VIII)

A general increase for lowland soil water was also noted for SO_4. However, some upland mixedwood soils intercepted considerable amounts of SO_4, and this occurred near the bottom of the rooting zone, as discussed in Chapter 6. Excluding such occurrences reduced the calculated variability of the SO_4 load of upland soil solutions considerably.

Watershed-level water-soluble and exchangeable ion loads are reported in Tables 19 and 20. The information in these tables is not too different from that shown in Table 18 for each of the two upland soil types, because the lowland contributions are generally small across the individual watersheds: lowland contributions, by area, range from 0.5% (Moosepit Brook) to 16.5% (Pebbleloggitch Lake).

Turnover Times for Ion Loads within the Rooted Soil Portions of the Watersheds

The turnover times for water-soluble and exchangeable ions in the rooted portion of the watershed soils varied significantly between ions, and between watersheds under mixedwood cover versus softwood cover (Tables 21 and 22). For water-soluble ion concentrations in soils, turnover times for ions such as H, Na, Cl, and Mg were short compared to turnover times for ions such as Fe, Ca, Mn, SO_4, K, Al and NO_3. For mixedwood watersheds, the sequence was:

$$NO_3>Al>>K>SO_4>Mn>Ca>Fe>Mg>Cl>Na>>H.$$

For softwood watersheds, the sequence was:

$$Al>NO_3>>K>Mn>SO_4>Ca>Fe>Mg>Cl>Na>H.$$

Hence, the ion-to-ion sequences were quite similar for both cover types.

Table 21. Turnover times† (in years) for water soluble ions in soil and stream water ion outputs

Watershed	Cl	NO3	SO4	Fe	H	K	Na	Mn	Ca	Mg	Al
MIXEDWOOD FORESTS											
Atkin's Brook	1.31	13.43	6.01	5.23	0.01	13.03	0.96	10.06	3.29	2.78	19.85
Mount Tom Brook	2.11	43.35	25.97	7.67	0.01	12.54	0.92	17.84	6.87	3.71	29.95
Pine Marten Brook	0.63	-	3.37	1.86	0.06	21.53	0.68	1.75	5.89	2.70	14.96
Pebbleloggitch Lake	0.87	21.98	8.91	5.53	0.02	6.00	0.37	5.80	7.38	4.14	22.59
Mixedwood Averages	**1.23**	**26.25**	**11.07**	**5.07**	**0.03**	**13.27**	**0.73**	**8.86**	**5.86**	**3.33**	**21.84**
Standard error	0.32	8.90	5.09	1.20	0.01	3.18	0.13	3.44	0.91	0.35	3.13
SOFTWOOD FORESTS											
Beaverskin Brook	0.59	-	2.84	-	0.30	8.70	0.92	2.79	2.65	1.31	49.29
Moosepit Brook	0.86	27.93	2.07	2.86	0.03	2.75	0.46	4.57	1.33	1.60	30.94
Roger's Brook	0.97	27.03	3.75	0.78	0.03	7.64	0.73	4.53	2.40	2.04	14.46
Softwood Averages	**0.81**	**27.48**	**2.89**	**1.82**	**0.12**	**6.36**	**0.71**	**3.96**	**2.13**	**1.65**	**31.56**
Standard error	0.11	0.37	0.48	1.04	0.09	1.84	0.13	0.59	0.40	0.21	10.06

† calculated as soil (eq/ha)/water output (eq/ha year)

Table 22. Turnover times† (in years) for exchangeable cations in soil and stream water ion outputs

Watershed	Fe	K	Na	Mn	Ca	Mg	Al
MIXEDWOOD FORESTS							
Atkin's Brook	12.7	133.5	0.7	283.5	15.5	13.1	492.2
Mount Tom Brook	12.6	77.4	0.2	186.9	16.1	9.7	268.2
Pine Marten Brook	17.5	212.1	0.8	43.2	41.3	15.7	362.6
Pebbleloggitch Lake	11.4	36.8	0.4	45.8	24.8	13.6	163.3
Mixedwood Averages	**13.5**	**115.0**	**0.5**	**139.8**	**24.4**	**13.0**	**321.6**
Standard error	1.3	38.0	0.1	58.5	6.0	1.3	69.9
SOFTWOOD FORESTS							
Beaverskin Brook	-	59.7	0.4	37.3	5.2	3.6	2157.1
Moosepit Brook	14.0	28.6	0.4	106.0	8.9	9.4	962.0
Roger's Brook	2.3	63.1	0.5	137.6	10.7	5.4	316.9
Softwood Averages	**8.2**	**50.5**	**0.4**	**93.6**	**8.3**	**6.1**	**1145.3**
Standard error	5.9	11.0	0.0	29.6	1.6	1.7	539.1

† calculated as soil (eq/ha)/water output (eq/ha year)

Turnover times, however, were generally shorter for softwood watersheds than mixedwood watersheds. Exceptions were H and Al. Turnover times for Na, Cl and NO_3 were almost equal for softwoods and mixedwood watersheds. In part, this is due to the higher ion loads within the soils of the mainly mixedwood watersheds, but also in part from a somewhat better retention of ions within these watersheds due to deeper rooting. The turnover time similarity for Na and Cl suggests that neither soil type was able to retain such ions very well. The case of NO_3-N, however, is special, because of the very low NO_3 loads of the streamwater itself, and its interception and likely retention within the immediate stream-soil transition zones (riparian ecotones). Also special is the case of the H ions, which - for the most part - are generated within the same transition zone on account of a general production of water-soluble organic matter with large numbers of organic acid groups but low N content (see Chapter 9).

The positioning of Al, SO_4 and K in the above sequences is noteworthy. For example, SO_4 turnover times are considerably longer than Cl turn-over rates, thereby suggesting that the watersheds do retain SO_4 to some extent. The same can be said for K, which, as already mentioned, would have a generally low mobility due to fixation on silicate mineral surfaces. Long turnover times for Al are certainly due to redistribution of mobilized Al within the soils and subsoils of the watersheds, and there is also the possibility that some of the Al so retained may form "alunite" in combination with K and SO_4 as already mentioned in the preceding Chapter.

Turnover times for exchangeable cations were all higher than the turnover times for water-soluble ions. Soils under mixedwood forest cover showed higher turnover times than soils under softwood forest cover except

for Al and Na. The ranking of longest to slowest turnover times was consistent for both watershed cover types, i.e:

Al>>Mn>>K>>Ca>Fe>Mg>>Na.

From a general forest nutrition perspective, it would appear that nutrient leaching would, on a relative scale, be highest for exchangeable Mg and lowest for exchangeable K, with exchangeable Ca falling in the middle. Hence, the soils at KNP, if subjected to enhanced ion leaching due to enhanced rates of atmospheric acid input, would lose the available Mg pools the fastest. Consequently, one can expect that forest trees within this area would eventually develop Mg deficiencies, and such deficiencies should manifest themselves first within the softwoods.

CONCLUSIONS

The following conclusions were made.

1. Mixedwood sites, which generally had deeper rooting, had larger total eq/ha ion concentrations.
2. Lowland sites had the same or larger ion pools than upland sites, especially for NO_3-N, Ca, Mg, and Al.
3. Lowland soils were more diverse (variable) than upland soils due to seepage and the associated ion loads.
4. Lowland contributions were relatively small at the watershed level, thus differences were not pronounced between each site type.
5. Turnover times varied between ions and between mixedwood and softwood sites.

6. The turnover times were generally shorter for softwood sites, except H and Al, due to the lower acidity under softwoods, where organic matter content is usually higher, thus redistributing Al and possibly retaining Al in combination with K and SO4 (alunite).
7. Na and Cl were not retained in any site type.
8. Exchangeable ion turnover times were longer than water-soluble ion turnover times.
9. In terms of forest nutrition, Mg was lost the fastest, then Ca and K.

CHAPTER 9

NITROGEN AND CARBON RELATIONSHIPS FOR SOIL ORGANIC MATTER AT KEJIMKUJIK NATIONAL PARK

INTRODUCTION

Atmospheric N deposition at KNP is considerable, yet N exports (NO_3-N, NH_4-N, organic N) from the watersheds through streamflow are negligible (see Chapter 4, page 60). The preceding chapters have shown that some uptake of N occurs in the forest canopy. As well, NO_3-N levels in the soil solution drop fairly steadily from topsoil to subsoil. Yet, some of the NO_3-N seeps through the soils, and accumulates in the soils along the wet spots, and in the lowlands. Altogether, it appears from the ion budget analysis in Chapter 5 that the watersheds at KNP are highly N undersaturated, and that N absorption, or extraction of N from the water as it percolates through the forest to the streams, occurs almost continuously. In this chapter, attention is focussed on the balance between N and C accumulations within soil organic matter, as expressed by the C/N ratios. For reference purposes, reference is made to the C/N ratio of dissolved organic matter (DOM) in streams and lakes, as already documented in Chapter 5.

The general objective for the work in this chapter was to hypothesize about and to verify the fate of the absorbed N on its path through the watersheds. For example, high C/N ratios would suggest that the soils at KNP are potentially capable of further N absorption. Low C/N ratios would

suggest that the soils are essentially N saturated. To test these hypotheses, it was decided to determine the C/N ratio of soil organic matter as it varies within the various soil layers that have already been described in the preceding chapters, and to check the mineralization rate of soil organic N in each of the sampled soil layers through an incubation experiment. High rates of N mineralization would be associated with soils that give off N readily, under field conditions.

METHODS

Portions of soil samples taken from KNP were oven-dried at 55 °C for 48 hours or more and then analyzed for total N (Kjeldahl method, through acid digestion and NH_4 distillation; McKeague 1978) and C (dry combustion with a Leco furnace; Bemner and Tabatabai 1971). Portions of moist samples were used for determining mineralizable NH_4-N, using 1 N KCl solutions to extract the mineralized NH_4-N from each soil (Bremner 1965). The moist soil portions were incubated for 7 days at 40°C (Page *et al.* 1982).

RESULTS AND DISCUSSION

Total nitrogen (%), carbon content (%), and C/N ratios are listed in Table 23 by soil layer type. Profiles for individual soils are graphically presented in Appendix VII (A-J). Both total N and C show the expected trends for the various soil profiles, being high in topsoils, and low in subsoils. In the forest floor, C/N ratios are relatively high (27 to 35). In the mineral soil, C/N ratios drop gradually with increasing soil depth from values of about 20 to values as low as 13.

Table 23. Total N, carbon, organic matter, and C/N ratios for soils measured in KNP

Stratum	Total N %	Carbon Content %	Organic Matter %	C/N ratio
		Lowland Soils		
Organic horizons	1.91	47.1	81.0	27
A horizons	0.74	16.1	27.7	21
Bf1 horizons *	0.15	2.3	4.0	15
Bf2 horizons *	0.10	1.6	2.7	15
Bg horizon	0.14	2.4	4.2	16
BC horizons *	0.14	2.4	4.1	17
		Upland Soils - Mixedwood Forest †		
Organic horizons	1.75	52.0	89.0	34
A horizons	0.11	2.2	3.8	19
Bf1 horizons	0.14	2.9	5.1	22
Bf2 horizons	0.09	1.6	2.7	17
BC horizons	0.06	0.8	1.3	13
C horizons	0.04	0.6	1.0	13
		Upland Soils - Softwood Forest ††		
Organic horizons	1.18	42.0	72.0	35
A horizons	0.12	2.4	4.1	17
Bf1 horizons	0.15	3.2	5.5	23
Bf2 horizons	0.10	1.8	3.1	20
BC horizons	0.06	0.9	1.5	17
C horizons	0.03	0.4	0.7	16

* only present in one soil pit

† Atkin's Brook, Mount Tom Brook, Pine Marten Brook, and Pebbleloggitch Lake watersheds -- predominantly mixedwoods

†† Beaverskin Brook, Moosepit Brook, and Roger's Brook watersheds -- predominantly softwoods

There are no major differences across the mixedwood, softwood and lowland soil types, except that C/N ratios are somewhat higher in areas where the forest litter decomposes less rapidly, i.e. bogs and fens (see Wood and Rubec 1989), lowlands and upland softwoods.

The general lack of C/N difference between lowlands and uplands is somewhat surprising, in view of the large C/N ratios of dissolved organic matter in streams and lakes. It follows from this that the source of organic matter in streams and lakes is not found in the soils of the area, but is likely located within the riparian ecotone. A review of the pertinent literature suggests that emerged and submerged macrophytes within this ecotone generate organic matter with a high C/N ratio, while stimulating denitrification by epiphytic denitrifying bacteriae (Weisner *et al.* 1994). Indeed, KNP streamwater that flows from boggy and swampy wetlands tends to be dark coloured on account of high DOC levels. Loss of N from the KNP wetlands through denitrification would be consistent with the fact that C/N ratios in wetlands generally range from 30 to 50 (Wood and Rubec 1989).

There were strong correlations between total C concentration, total N concentration and mineralizable NH_4-N (Fig. 22). In particular, mineralizable NH_4-N was directly proportional to total N, and net NH_4 mineralization in the forest floor samples exceeded net NH_4 mineralization in the mineral soil samples by a factor of 10. Net NH_4 mineralization was also influenced by the C/N ratio according to site type. There were two effects: (*i*) mineralizable NH_4-N decreased with increasing C/N ratio in the forest floor, and; (*ii*) mineralizable NH_4-N decreased with increasing C/N ratio in the mineral soil.

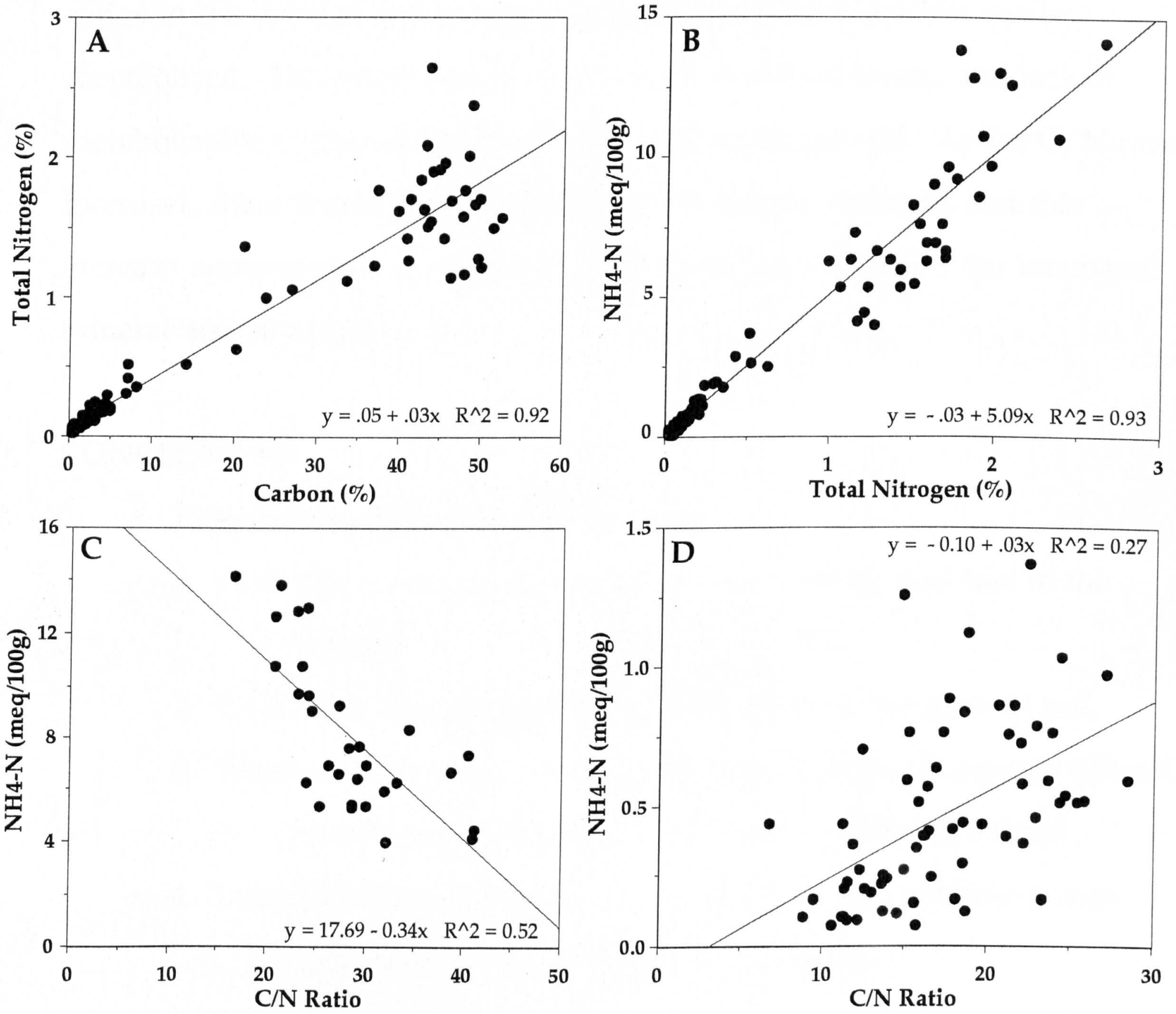


Fig. 22. Regression analysis using watersheds in or near Kejimkujik National Park:
(**A**) Total nitrogen (%) versus carbon (%) using all horizons;
(**B**) NH4-N (meq/100g) versus total nitrogen (%) using all horizons;
(**C**) NH4-N (meq/100g) versus C/N ratio using only organic (F,H) horizons;
(**D**) NH4-N (meq/100g) versus C/N ratio using only mineral horizons (excluding Ah and Ahe horizons).

It is suggested that the metabolizable C portion of the forest floor increases with increasing C/N ratios, thereby encouraging net NH_4-N immobilization at high C/N ratios. It is further suggested that organic matter with low C/N ratios in the mineral soil is highly humified and therefore less easily metabolized. This effect would be strongest in subsoil layers, and lack of metabolizable C discourages microbial activities in general. As the C/N ratio increases, there would be a small increase in metabolizable C, and this increase appears to stimulate net NH_4 mineralization within the incubated mineral soil samples.

CONCLUSIONS

Conclusions that were made include:

1. C/N ratios were generally high in the topsoils, and low in the subsoils.
2. C/N ratios dropped gradually with depth in the mineral soil.
3. There were no major differences between the C/N ratio in upland mixedwood, upland softwood, and lowland soil types.
4. Loss of N from wetlands by denitrification was consistent with C/N ratios documented for the wetlands.
5. Net NH_4 mineralization in the forest floor exceeded net NH_4 mineralization in mineral soil by a factor of 10.
6. Mineralizable NH_4-N decreased with increased C/N ratios in the forest floor, and mineralizable NH_4-N decreased with increased C/N ratios in the mineral soil.

CHAPTER 10

GENERAL CONCLUSIONS

In this thesis, an attempt was made to link vegetation type, soil type and landform associations with streamwater quality through data analysis. Also examined were watershed nutrient budgets, chemical composition of water in the soil, and estimations of cations on exchange sites in the soil. It was found that watersheds at KNP do not vary much in terms of climate, vegetation type and topographical conditions. This has made it difficult to draw general conclusions in terms of the original formulation (Chapter 1). However, differences were found in water quality among watersheds with respect to the timing (and magnitude in some cases) of maximum and minimum concentrations of particular ions. Stream type (lake inlet versus lake outlet) was the main contributor to these differences, and also to the differences found for nutrient budgets among watersheds. Nutrient concentrations in the soil solutions differed among watersheds depending on the dominant vegetation types supported by the soils. Patterns emerged within soil profiles, specific to the August conditions when soils were sampled. Exchangeable cation concentrations followed the same patterns, but differences among watersheds were not as pronounced. Soils under softwood forest cover had higher turnover times (calculated as total soil ion concentration/streamwater ion concentration flux ratios) than soils under mixedwood forest cover, except for H and Al. The ranking of longest to

fastest turnover times for each ion was consistent for both watershed cover types. In terms of forest nutrition, Mg was lost the fastest, then Ca and K.

SUMMARY

Streamwater quality at Kejimkujik National Park is ultimately affected by many contributing factors. This thesis attempted to identify the effects of several factors influencing the water that reaches the streams. These included: (*i*) atmospheric inputs (rain, snow, fog, dry deposition); (*ii*) alteration of these atmospheric inputs by vegetation (throughfall and stemflow); (*iii*) contact with water in the forest floor and soil complexes (including geological influences; i.e. weathering); (*iv*) topography and landform (slope, compaction, and seepage pathways); (*v*) further influences of wetland vegetation close to the streams, and; (*vi*) lake and streamwater characteristics (residence time, colour, lake inlet versus lake outlet). Each of these factors can affect both the volume and chemical composition of the streamwater.

Atmospheric inputs to the watersheds at Kejimkujik National Park were assumed to be the same for each watershed, hence, differences in elevation or aspect were not considered. In general, precipitation in this region is very acidic, influenced by westerly winds carrying pollutants from the heavily industrialized eastern United States and Canada. Marine influence in this area is evident in the high concentrations of Na and Cl in both precipitation and fog water. These salts can also accumulate in dry deposition. Lowest volumes of precipitation occur in the late summer and early fall, with highest volumes in the spring. These patterns are reflected in the timing of flow in the streams.

Vegetation alters the atmospheric inputs as throughfall and stemflow. This alteration would only affect small amounts of water that eventually reaches the forest floor, but the overall effect would be expected to be significant in a forest setting. In the Beaverskin Lake and Pebbleloggitch Lake watersheds, throughfall and stemflow were found to increase the concentrations of K, Na, Mg, Ca, and SO_4. NH_4 and NO_3 had lower concentrations in water caught as stemflow and throughfall, due to absorption by the surfaces of the vegetation.

It was found that watersheds containing mainly mixedwood forests tend to have higher nutrient concentrations and loads in their soil solutions than sites containing mainly softwood forests. In addition, the chemical composition of lowland soil solutions were much more variable (more diverse) than the chemical composition of upland soil solutions. A likely factor that contributed to this variability was a spatially variable pattern of subsoil seepage flow.

Water-soluble ion concentrations in the soils of KNP in August after weeks of dry weather showed several patterns: (*i*) ion concentrations in surface soil layers (forest floor) were high, likely due to retention of ions by ion exchange (ion exchange sites tend to be in equilibrium with ions in solution) and ion complexation with organic matter; (*ii*) reduced nutrient ion concentrations in heavily rooted layers (root uptake of NO_3-N especially); (*iii*) seepage through the soil was likely responsible for high ion concentrations at the interface between the uncompacted topsoil and the compacted subsoil, and; (*iv*) seepage was also likely responsible for much enhanced ion concentrations along wet spots and in lowland soils.

Soils under mixedwoods tended to contain higher levels of water-

soluble ions, especially Ca, Mg, K. Mixedwood soils also seemed to have a higher degree of ion retention than softwood soils: mixedwood soils had higher concentrations of base cations (Ca, Mg, K) in the subsoil solution than softwood soils. In general, August streamwater concentrations were lower than subsoil water concentrations. Among the soil solutions, subsoil solutions resembled the streamwater concentrations in ion composition the most.

Na was the most mobile element in both the forest floor and the mineral soil, with little extra Na to be found on the ion exchange sites. Calcium and Mg were also fairly mobile in both soil layer types, with a considerable portion of the available Ca and Mg being present in the soil solution. Water solubilities of K, Mn, and Al were low in comparison with the amounts of K, Mn, and Al that could be found on the cation exchange sites. A high proportion of Fe that is available tends to be in the soil solution of the mineral soil.

A greater diversity for total ion concentrations in soil solutions (eq/ha) was found in lowland sites than was noted in upland sites. Lowland contributions to the whole watershed ion load in soil solution, were, however, small across all watersheds.

Exchangeable cations in the soils of KNP revealed a pattern similar to that of the water-soluble ion concentrations, but differences between upland and lowlands, and mixedwood and softwood sites were generally not as pronounced as the differences found with water-soluble ions.

The chemical composition of streamwater in the KNP watersheds differ according to season, stream type (lake inlet versus lake outlet), and the influence of wetlands. Na, Cl, Mg, and Ca had high concentrations in late fall

and sometimes in winter, and low levels during spring, reflecting: (*i*) seasonal trends of precipitation; (*ii*) storage by water-unsaturated soils; (*iii*) vegetative uptake and retention in soil by partial absorption on clay mineral surfaces, and; (*iv*) dilution in spring. Lake inlets tended to have higher and more variable concentrations than lake outlets, due to the increased residence time in lakes delaying the peak response for Mg, Na, and Cl. The geological contributions of greywacke versus granite explain the differences between lake inlet and lake outlet Ca and Mg concentrations.

K concentrations in streamwater were small, due to high uptake rates by vegetation, high absorption rates by clay minerals in the soils, and high rates of return of K into soil solids through K-fixation.

Dissolved organic matter, originating from the wetland portions of the watershed, complex with Al, Fe, and Mn, resulting in similar patterns for the concentrations of these species in streamwater: mainly highest in mid-summer and lowest in winter and spring. A lag of 3 months was found for maximum DOC levels in lake outlets and higher order streams, on account of large storage capacity and long water residence time.

Streamwater H, SO_4 and NO_3-N concentrations were lowest during summer low flow, and highest during fall and winter. SO_4 is affected by atmospheric deposition, some is temporarily stored in organic matter, and further increases may be due to washoff of dry SO_4 deposition, evapotranspiration, low water table and decreased runoff in summer. There were notable seasonal variations in streams located as lake inlets versus those located as lake outlets. Nitrate concentrations were very variable, and low overall. N uptake by vegetation, and lack of high rates of nitrification in soils of the area were both reasons for the resulting pattern over seasons.

Wetlands and wet soil pockets adjacent to streams acted as nutrient pools, presumably causing episodic injections of high nitrate waters in streamwater during major precipitation events, especially during vegetational dormancy.

Watershed ion budgets for atmospheric inputs versus streamwater outputs were calculated with precipitation, fog water and dry deposition. It was found that fog water and dry deposition contributions make significant contributions to the watershed ion balances. For example, there would be a serious mismatch between the Na and Cl inputs and outputs for each of the monitored watersheds if fog and dry deposition were not considered.

Watersheds at KNP were found to be strongly N undersaturated (output << inputs), partially saturated with respect to H ions and S (outputs slightly less than inputs), and fully saturated with respect to Na and Cl (outputs ≈ inputs). Potassium ions were also retained. With respect to N, it was found that most of a substantial part of the incoming N is taken up by the vegetation on uplands soils. Wetlands also contribute to the N budget, either through vegetative uptake and related immobilization, or through denitrification, before the water enters the stream itself.

ORIGINAL CONTRIBUTIONS

This thesis provides new information as follows.

1. A nearly up-to-date summary and analysis of the available hydrogeochemical data available for KNP (wet and dry deposition, throughfall, soil solution, and streamwater).
2. Soil solution data are original to this thesis.

3. The first realistic formulation of the ion budgets across nine watersheds, characterized as lake inlets or outlets as the case may be.
4. An in-depth and integrative modelling attempt of water and heat flows through the watersheds, from weather information to the simulation of stream discharge records.
5. A data analysis that links atmospheric deposition data with soil solution data and streamwater quality data.
6. An appraisal of the influence of watershed type (forest cover type) on streamwater quality.
7. An analysis of the C/N ratio of organic matter (in uplands, lowlands, wetlands, and streamwater).

SUGGESTIONS FOR FURTHER WORK

Suggestions for further work include: (*i*) incorporating the data summaries and findings into a presentation tool (ToolBook) that links with a Geographical Information System (GIS) in order to provide users with a method of accessing information related to map positions; (*ii*) repeating soil sampling efforts at different times of the year to see if trends of soil ion compositions are consistent; (*iii*) developing models that incorporate the influence of both the lowland and uplands soils at the watershed level; (*iv*) generating ion flow models that address the complications of seepage flows and summer drought effects on ion pools in the soils, and; (*v*) measuring and monitoring fog water chemical composition and dry deposition at the Park.

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APPENDICES

APPENDIX I

TREE SPECIES ABBREVIATIONS FOR TABLE 3

Be	beech
bF	balsam fir
bS	black spruce
eL	eastern larch or tamarack
gB	grey birch
He	eastern hemlock
ltA	large-tooth aspen
rM	red maple
rO	red oak
sM	sugar maple
stM	striped maple
tA	trembling aspen
wB	white birch
wP	white pine

APPENDIX II

GROUND VEGETATION KEY FOR TABLE 3

1 acuminate aster *Aster acuminatus* Michx.
2 bazzania *Bazzania trilobata* (L.) S.F. Gray
3 beaked hazel *Corylus cornuta*
4 black huckleberry *Gaylussacia baccata*
5 bog laurel *Kalmia polifolia* Wang.
6 bog rosemary *Andromeda glaucophylla* Link
7 bracken fern *Pteridium aquilinum* (L.) Kuhn
8 broom moss *Dicranum scoparium* Hedw.
9 bunchberry *Cornus canadensis* L.
10 caribou moss *Cladina stellaris* (Opiz.) Brodo.
11 choke cherry *Prunus virginiana* L.
12 chokeberry *Pyrus arbutifolia* (L.) L. f.
13 cinnamon fern *Osmunda cinnamomea* L.
14 common blackberry *Rubus allegheniensis*
15 common hair-cap moss *Polytrichum commune* Hedw.
16 creeping snowberry *Gaultheria hispidula* (L.) Muhl.
17 cucumber-root *Medeola virginiana* L.
19 dwarf raspberry *Rubus pubescens* Raf.
20 false lily-of-the-valley *Maianthemum canadense* Desf.
21 gold thread *Coptis trifolia* (L.) Salisb.
22 grasses *Graminae* sp.
23 ground cedar *Lycopodium tristachyum* Pursh
24 ground pine *Lycopodium obscurum* L.
25 hay-scented fern *Dennstaedtia punctilobula* (Michx.) Moore
26 Indian-pipe *Monotropa uniflora* L.
27 interrupted fern *Osmunda claytoniana* L.
28 juniper hair-cap moss *Polytrichum juniperinum* Hedw.
29 Labrador tea *Ledum groenlandicum*
30 lady fern *Athyrium felix-femina* (L.) Roth
31 lady-slipper *Cypripedium acaule* Ait.
32 lambkill *Kalmia angustifolia*
33 leatherleaf *Chamaedaphne calyculata* (L.) Moench

34 long beech fern *Thelypteris phegopteris* (L.) Slosson
35 low, sweet blueberry *Vaccinium angustifolium*
36 mayflower *Epigaea repens* L.
37 meadow sweet *Spiraea alba* Du Roi var. *latifolia* (Ait.) Anles
38 mnium moss *Mnium* sp.
39 mountain-fern or step moss *Hylocomium splendens* (Hedw.) B.S.G.
40 mountain-holley *Nemopanthus mucronata*
41 nake miterwort *Mitella nuda* L.
42 New York fern *Thelypteris noveboracensis* (L.) Nieuwl.
43 oak fern *Gymnocarpium dryopteris* (L.) Newm.
44 painted trillium *Trillium undulatum* Willd.
45 plume moss *Ptilium crista-castrensis* (Hedw.) DeNot.
46 ptilidium *Ptilidium pulcherrimun*
47 purple trillium *Trillium erectum* L.
48 red baneberry *Actaea rubra* (Ait.) Willd.
49 reindeer moss *Cladina rangiferina* (L.) Harm.
50 rhodora *Rhododendron canadense*
51 roses *Rosa* sp.
52 running clubmoss *Lycopodium clavatum* L.
53 running pine *Lycopodium complanatum* L.
54 sarsaparilla *Aralia nudicaulis* L.
55 Schreber's moss *Pleurzium schreberi* (Bid.) Mitt.
56 sedges *Carex* sp.
57 sensitive fern *Onoclea sensibilis* L.
58 shining clubmoss *Lycopodium lucidulum* Michx.
59 Sphagnum moss *sphagnum* sp.
60 starflower *Trientalis borealis* Raf.
61 sweet gale *Myrica gale* L.
62 sweet-fern *Comptonia perigrina*
63 three leaf rattlesnake-root *Prenanthes trifoliolata* (Cass.) Fern.
65 velvetleaf blueberry *Vaccinium myrtilloides*
66 violets *Viola* sp.
67 Wavy dicranum *Dicranum polysetum* Sw.
68 white baneberry *Actaea pachypoda* Ell.
69 wild raisin *Viburnum cassinoides*
70 wild red raspberry *Rubus strigosus* Michx.
71 willows *Salix* sp.
72 wintergreen *Gaultheria procumbens* L.
73 witch-hazel *Hamamelis virginiana*
74 wood fern *Dryopteris austriaca* (Jacq.) Woynar
75 wood-sorrel *Oxalis montana* Raf.
76 yellow clintonia *Clintonia borealis* (Ait.) Raf.

APPENDIX III

FOREST COVER TYPES FOR TABLE 4

(From Gimbarzevsky 1975)

SFP-MB	Spruce, fir, pine with maple and birch
SHP-MB	Spruce, hemlock, pine with maple and birch
SFP-MOB	Spruce, fir, pine with maple, oak and birch
MOB-PS	Maple, oak, birch with pine and spruce
SFPH	Spruce, fir, pine and hemlock
MOBBe	Maple, oak, birch and beech
PS-MB	Pine, spruce with maple and birch

APPENDIX IV

SOIL FIELD DATA SUMMARY

Watershed	Horizon	Depth (cm)	Texture *	Structure **	Consistence	Roots +	Boundary	Coarse Frag's ++	Other
Mount Tom Back Ridge	**L**	4.5-4							-pine needles, twigs, oak, rM, alder leaves
	F	4-2				a mi - f f m - c			-partially decomposed above (matted)
	H	2-0				p mi - f f m - c			-fully decomposed material -rusty brown rather than black
	Ae	0-2	SL	fine sab-loose	loose	p f m	abrupt smooth	<5% g	-more orange than
	Bf1	2-14	SL	fine-med sab	friable	p f m	clear wavy	10-20% g - c	Atkin's and Roger's Brook
	Bf2	14-34	SL	fine-med sab	friable - loose	p f m, f c	clear wavy	20-30% c 40% s - b	
	BC1	34-60	SL	med-coarse sab	friable	f f m, f c		30% c 40% s - b	-f c roots grew b/n rocks and boulders
	BC2	45-50	SL	f sab - loose	friable	none	abrupt broken	30% c 40% s - b >70% c - s at bottom	-lighter color than BC1
Mount Tom Front Ridge	**L**	2.5-2							-oak, rM leaves and twigs
	F	2-0				a mi - f f m - c			partially decomposed above
	Aej	0-3	L	f sab - loose - weak	loose - friable	p vf - f f m - c	abrupt broken	<5%	
	Bf1	3-18	L	loose - weak - f sab	loose - friable	p f - m f c	clear wavy	<5%	
	Bf2	18-48	L	loose - weak - f sab	loose - friable	f f - m	clear wavy	<5%	
	BC	48-75 +	L	mod m sab	friable - firm	f m	?	5%-8% g - s	-roots could go deeper than this layer

SOIL FIELD DATA SUMMARY

Watershed	Horizon	Depth (cm)	Texture	Structure	Consistence	Roots	Boundary	Coarse Frag's	Other
Atkins North	**F**	4-0				a mi - f			-yellow fungus present on roots
Ridge	**Ae**	0-4	L	weak f sab	friable	f f - m	abrupt wavy	10% fine ang g	
	Bf1	4-16	L	weak mod f sab	friable	p f - m f c	clear wavy	5-10% fine ang g	
	Bf2	16-30	L	weak f sab	friable	f f - m f c	clear wavy	5-10% fine ang g	
	BCj1	30-50	SL	mod f - c sab	firm	none	abrupt broken	10% g	
	BC2	30-50	SL	weak c sab	firm	none	clear broken	20% g - s	
	C	50+	SL	weak f sab - loose	friable - firm	none		30% g - s	
Atkins Ridge	**L**	3.5-3.0							-thin litter of wP needles, twigs, oak leaves, mosses and wood
	F	3.0-0				a mi - f f c			-yellow fungus present on roots
	Ae	0-2	L	weak sab - loose	friable	f f	abrupt smooth	10-20% fine ang g	-dry to moist soil
	Bf1	2-14	L	mod sab - gran	friable	p f - m vf c	clear wavy	10-20% ang g	-Bf layers could be Bm
	Bf2	14-29	L	mod sab	friable - firm	f f - m	clear wavy	5% ang g	
	BC1	29-49	SL	weak sab	firm	vf f - m	clear wavy	10% ang g	
	BC2j	29-39	SL	weak sab	firm	none	abrupt broken	10% ang g	
	C	49+1	SL	very weak sab - loos	firm - friable	vf c	not seen	20% ang g - c	
Pine Marten	**L**	9.5-9.0							-beech leaves, oak leaves
Ridge	**F**	9-4				a mi - f f m - c			-abrupt, smooth boundary -micchorhyza on roots
	H	4-0				p mi - f f m - c			
	Ae	0-3	SL	mod f sab	friable - firm	f f - m	abrupt broken	5% fine g frag's	-slate (fine particles)
	Bf1	0-15	L	mod f -m sab - gran	friable	p f f m	clear wavy	<5% g - s	-Bf layers could be Bm
	Bf2	15-35	L	fine - med sab mod	friable	f f vf m	clear wavy	<5% g - s	
	BC	35-55	SL	med sab mod	firm	vf f	clear smooth	10% fine g frag's 5% g	
	C	55+	SL	med-c sab blky	firm-hard	none			

SOIL FIELD DATA SUMMARY

Watershed	Horizon	Depth (cm)	Texture	Structure	Consistence	Roots	Boundary	Coarse Frag's	Other
Pine Marten Ridge 2	**F**	4-0				a mi - f f m			
	Aej	trace							
	Bf1	0-20	SiL	loose - weak f sab	loose - vfriable	p f - m	clear smooth	5%	
	Bf2	20-40	SiL	loose - weak f sab	loose - vfriable	f f -m	clear smooth	5%	
	BC	40+	L	weak m sab	friable	none	not seen	35% g - c	
Pebbleloggitch	**L**								-pine, oak, maple leaves
	F	5-0.5				a mi - f			-yellow fungus on roots
	H	<0.5				a mi - f f m - c			-roots run along bottom of H/Ae interface
	Ae	0-12	SL	med sab mod	friable	f f - m vf c	abrupt irregular	5% c 10% b	-abrupt smooth boundary -coarse frag's not many stone size
	Bf1	12-22	L	weak f sab	friable	p f - m vf c	clear wavy	10% c 5% b	-granite pm
	Bf2	22-32	SL	mod f - m sab	friable	p f - m vf c	clear wavy	10% c 5% b	
	BC	32-44	SL	mod m - c sab	friable - firm	f f - m vf c	clear smooth	5% b	
	C	44+	SL	mod sab	friable	vf c		10% c 5% b	-less than vf but some mod roots going down to 80 cm H20?
Roger's Brook Hemlock Ridge	**L**	4-3							-oak leaves, twigs, cones, maple leaves, He and rS needles
	F	3-0				p mi - f			-decomposed He needles and cones
	Ah	0-5	L	weak f - m g	friable	p f - m f c	clear smooth	<5%	-might be disturbed
	Bf1	5-12	L	weak f - m g	friable	p f - m f c	clear smooth	5% c - s	-Bf layers may be Bm
	Bf2	12-70	L	f sab	friable	f f - m f c	clear smooth	5% c - s	- 80% of volume
	Aej	12-20	SiL	f sab	firm	vf f	broken abrupt	0%	-10% or less by volume
	BC	70+	SL	f sab	firm				

SOIL FIELD DATA SUMMARY

Watershed	Horizon	Depth (cm)	Texture	Structure	Consistence	Roots	Boundary	Coarse Frag's	Other
Roger's Brook	**L**	3-2							-pine needles, twigs,
Pine Ridge	**F**	2-0							-decomposing above
	Ahe	0-5	L	mod m gran	friable	p f - m f c	clear smooth	none	
	Bf1	5-10	L	weak m gran	friable	p f - m vf c	clear smooth	5-10% ang g	-Bf layers may be Bm
	Bf2	10-32	L	weak f sab	friable	f f	clear smooth	5% ang g	
	BC	32+	LS	weak m sab	very firm	none		10% ang g - c	-grey in color
Beaverskin	**F**	3-0				a mi - f			-not layered but a mat
Ridge						vf m - c			-abrupt smooth boundary
	H	trace				p mi - f f m - c			-roots run along H/Ae interface
	Ae	0-12	SL	weak sab	friable - loose	f f f m - c	abrupt irregular continuous	0%	
	Bf1	12-22	SL	weak sab - loose	friable - loose	p f f m	clear wavy	5% c - s 10% b	
	Bf2	22-34	SL	mod f - m sab	friable - loose	f f - m	abrupt smooth	5% c - s 10% b	
	BC	34-46	SL	mod - s m sab	firm	vf f - m	abrupt smooth	10% c	
	C	46+	SL	mod m sab	friable - firm	vf m		10% g - c	-not as deep as Pebbleloggitch
Moosepit Brook	**F**					a m - f			
Road						f m - c			-charcoal layer in H
	H	<1cm							finer roots in F
									coarser roots in FH/Ae interface
	Aej	0-3	L	mod m sab	friable - firm	f f - m	abrupt broken	<5% c - s	-charcoal present
	Bf1	0-12	L	mod f sab	friable	f f	clear wavy	<5% c - s	-mineral soil is not heavily
	Bf2	12-24	L	mod f sab	friable	f f	clear wavy	<5% c - s	exploited by roots
	BC	24-42	SL	mod m sab	friable - firm	vf f	clear smooth	<5% c - s	
	C	42+	SL	strong m sab	firm	none		10% f ang g frag's	

SOIL FIELD DATA SUMMARY

Watershed	Horizon	Depth (cm)	Texture	Structure	Consistence	Roots	Boundary	Coarse Frag's	Other
Moosepit Brook	**F**	3-1				a m - f			-abrupt smooth boundary
Open						f m - c			-no charcoal
	Ae	0-2	SiL	med sab	friable - loose	f f - m	abrupt wavy	<5%	-moist soils even on ridge
	Bf1	2-14	L		friable - loose	f f	clear wavy	<5%	
	Bf2	14-28	SL	mod-strong sab	firm - hard	f f	clear wavy	<5%	
	BC	28-42	SL		firm		clear smooth	10% g frag's	
	C	42+	SL		firm			15% g frag's	

* S=sand, L=loam, SiL=silty loam, SL=sandy loam

** mod=moderately, med=medium, f=fine, c=coarse, sab=subangular blocky, g=granular

+ a=abundant, p=plentiful, f=few, vf=very few, ff=few,fine, m=medium, c=coarse

++ g=gravel, c=cobble, s=stone, b=boulder

APPENDIX V

WATER-SOLUBLE ION CONCENTRATIONS OF ORGANIC AND MINERAL SOIL HORIZONS IN KEJIMKUJIK NATIONAL PARK

Each graph (A through T) illustrates water-soluble ion concentrations (meq/100g) for soil pits dug at 21 different locations [upland and lowland (or "grab") soils]. The horizontal width of each horizon approximates depth.

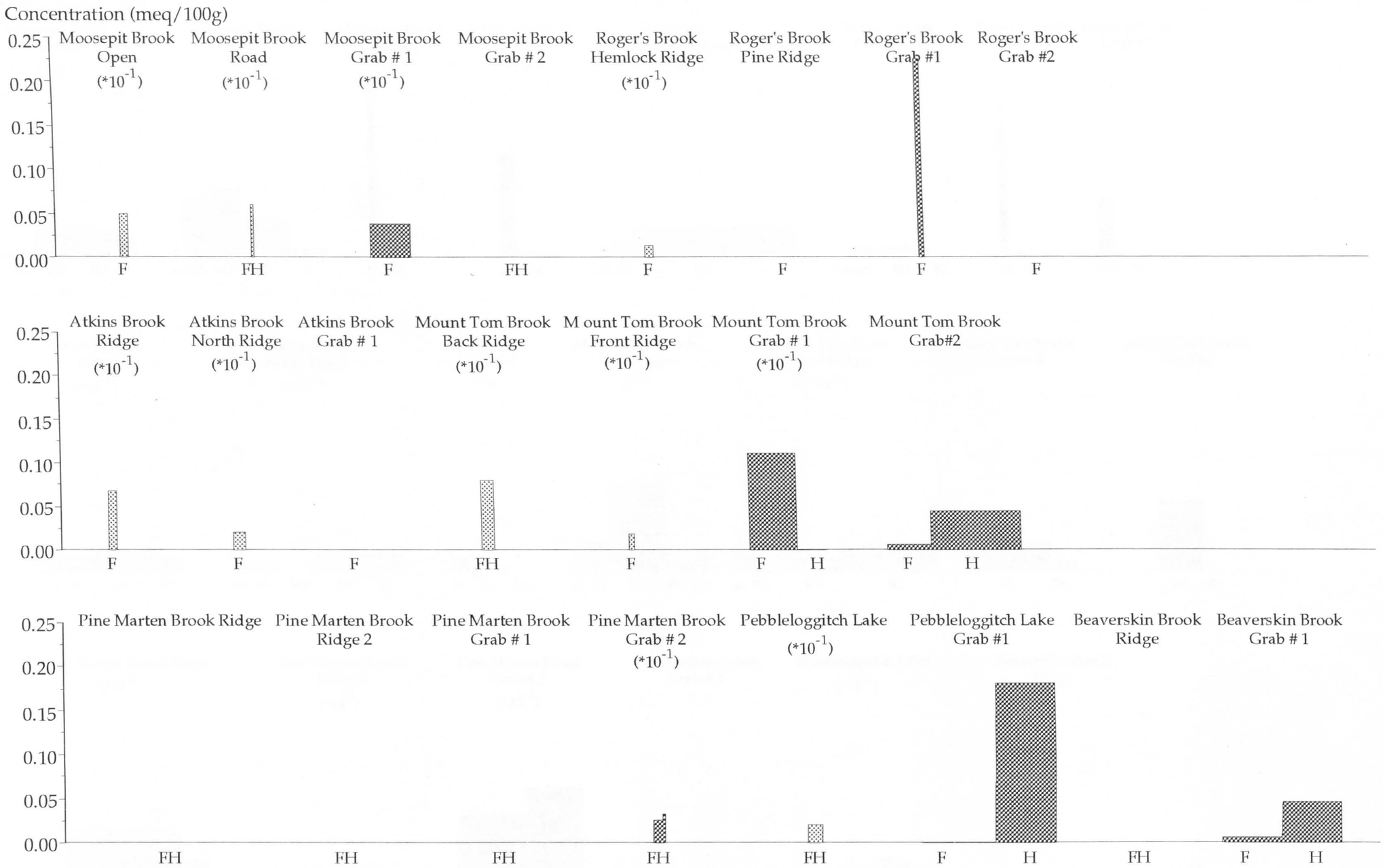
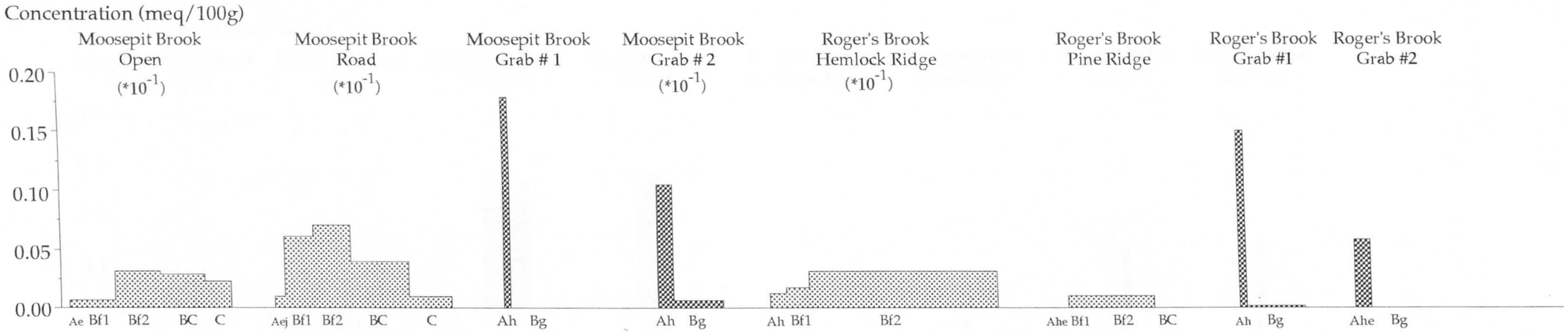
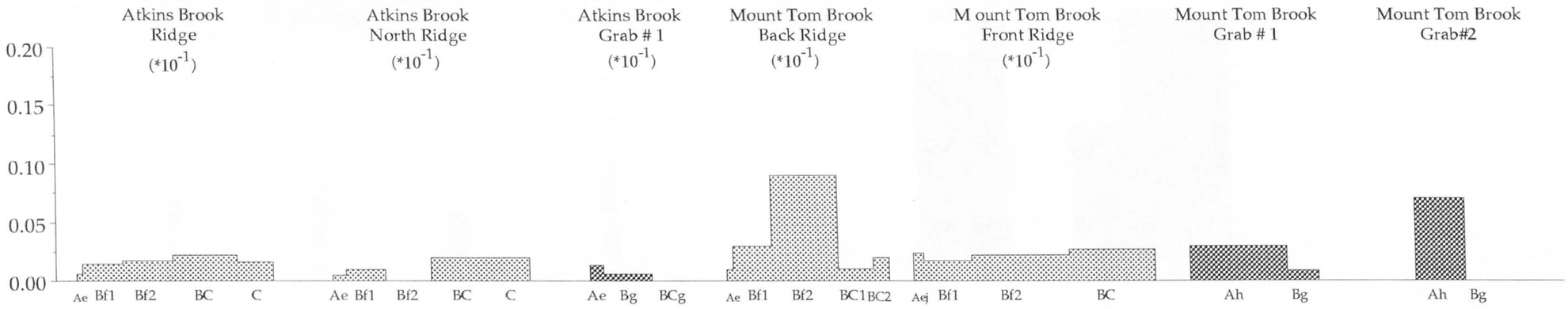


Fig. V A. Water-soluble nitrate concentrations (meq/100g) for organic horizons (upland soils; lowland soils).





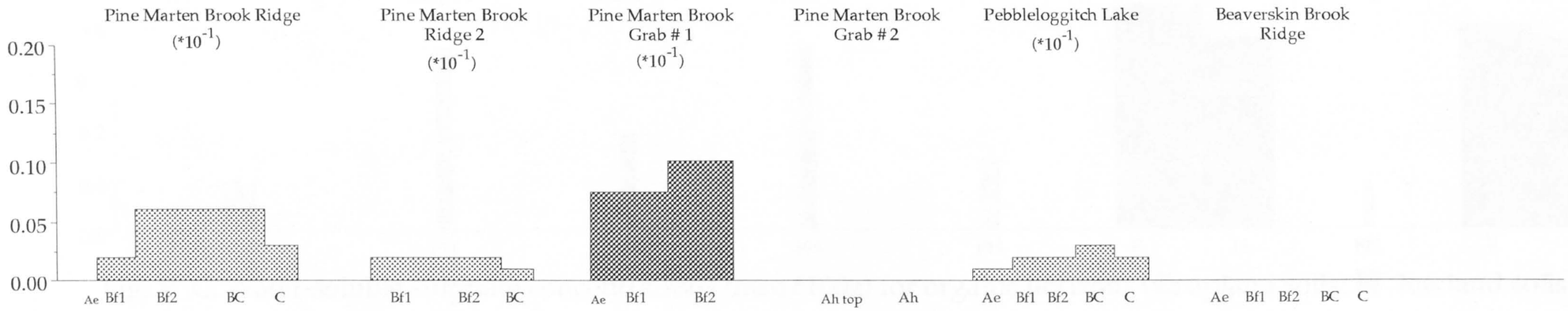


Fig. V B. Water-soluble nitrate concentrations (meq/100g) in mineral soil horizons (▨ upland soils; ▩ lowland soils)

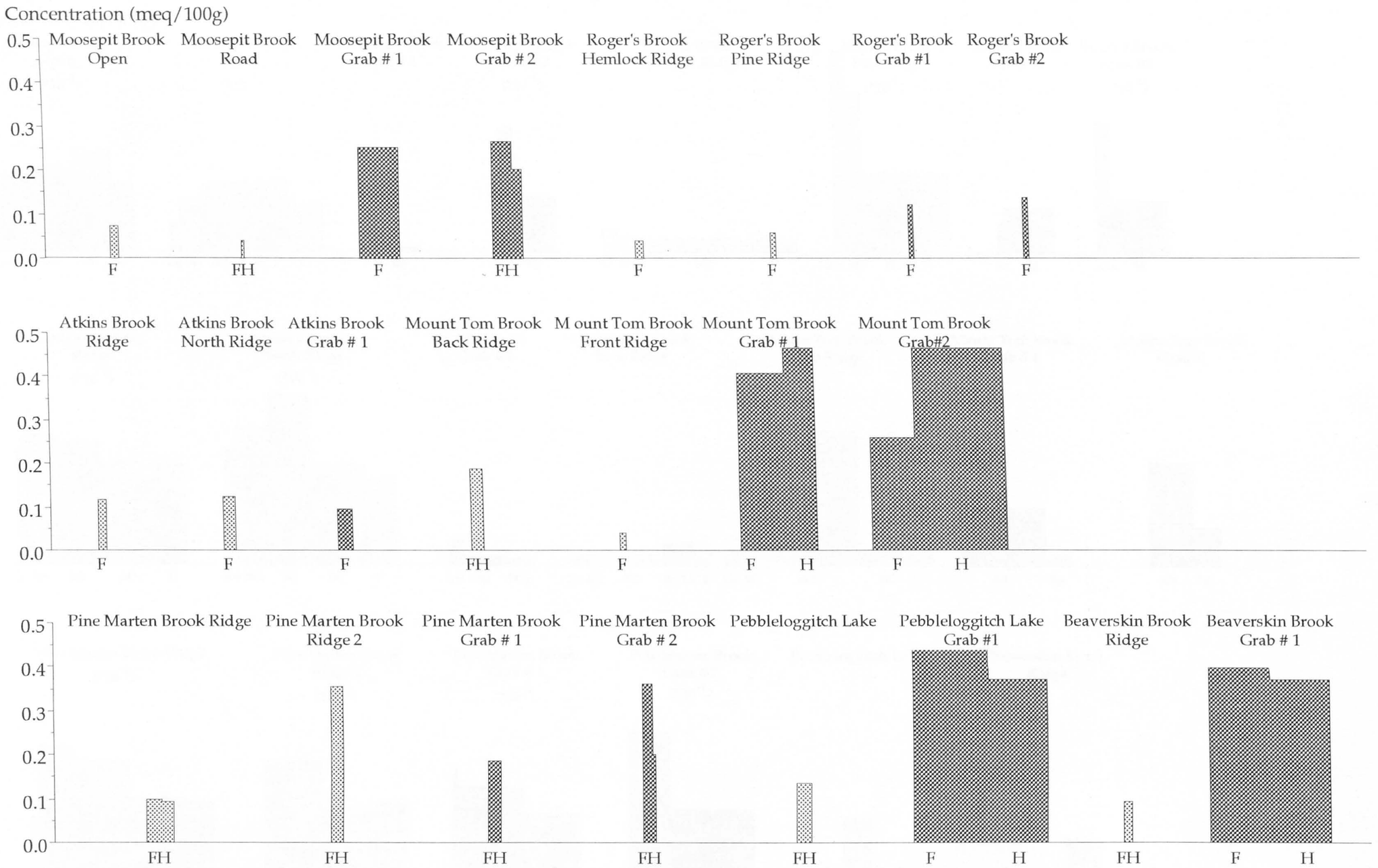
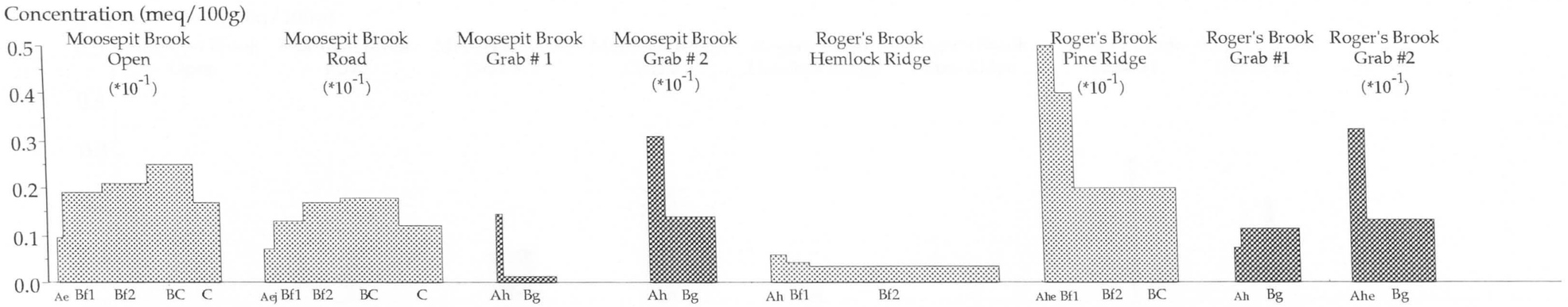
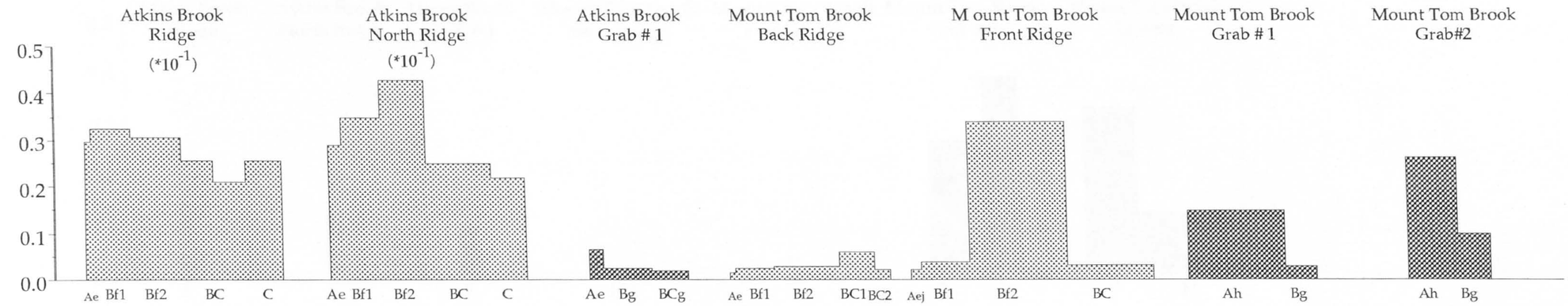


Fig. V C. Water-soluble sulphate concentrations (meq/100g) for organic horizons (upland soils; lowland soils).





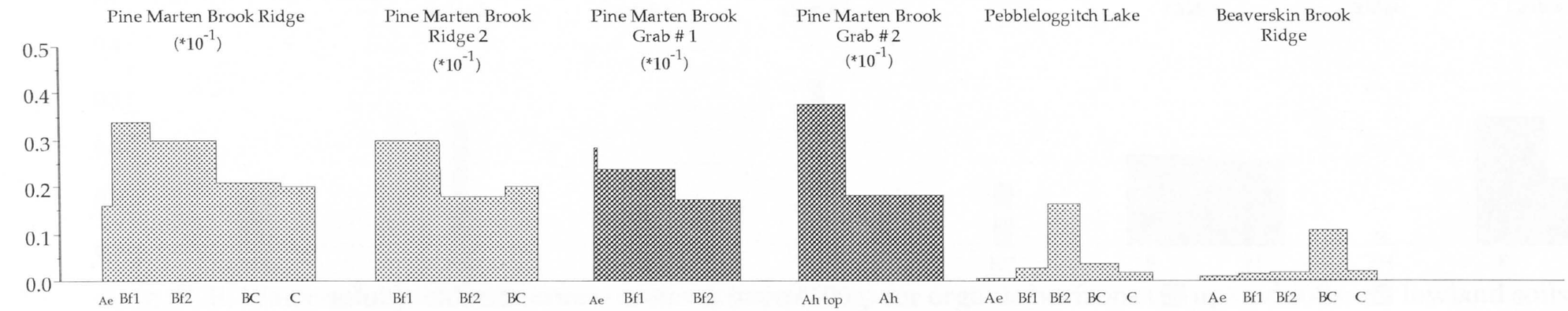


Fig. V D. Water-soluble sulphate concentrations (meq/100g) in mineral soil horizons (upland soils; lowland soils)

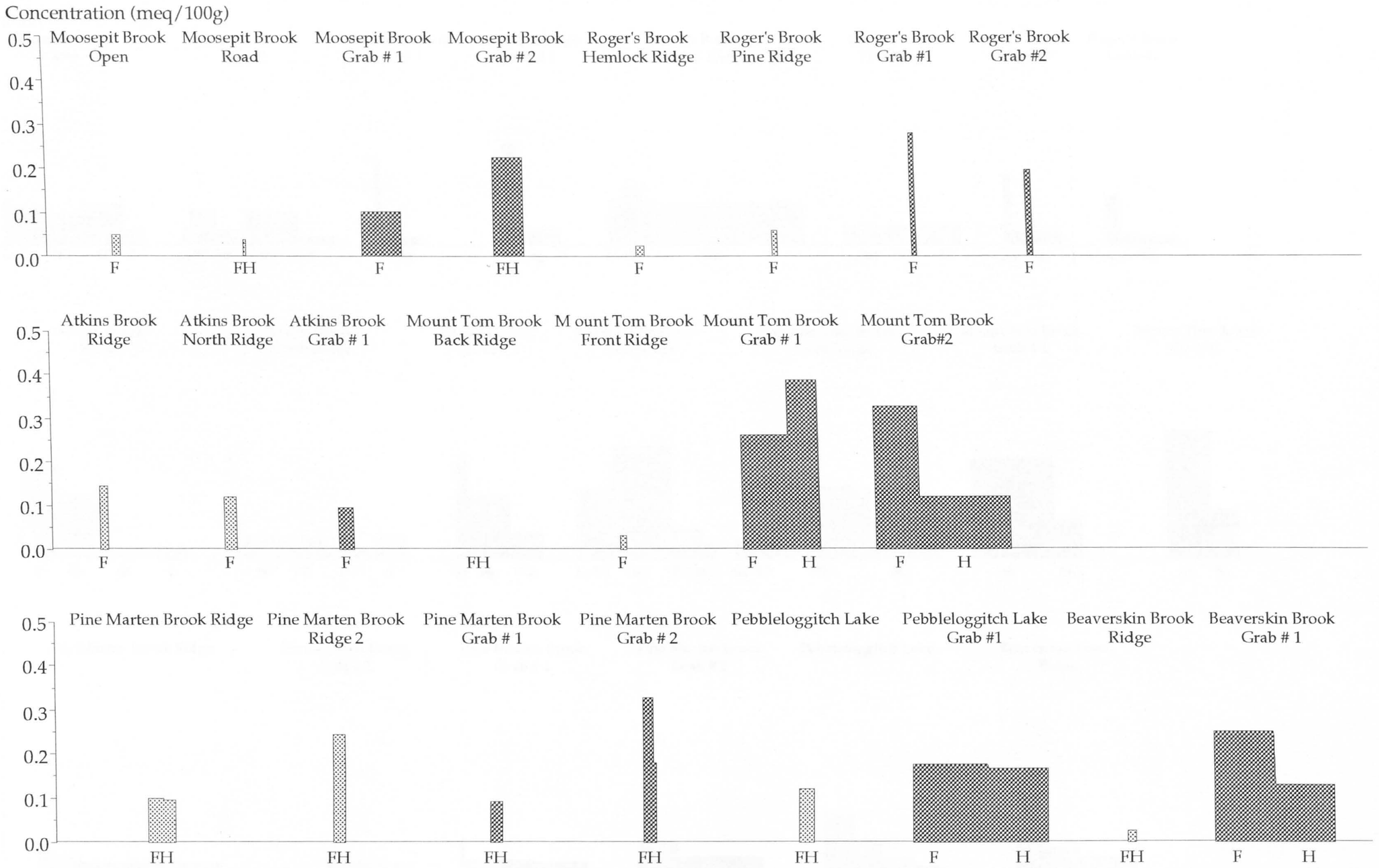


Fig. V E. Water-soluble chlorine concentrations (meq/100g) for organic horizons (upland soils; lowland soils).

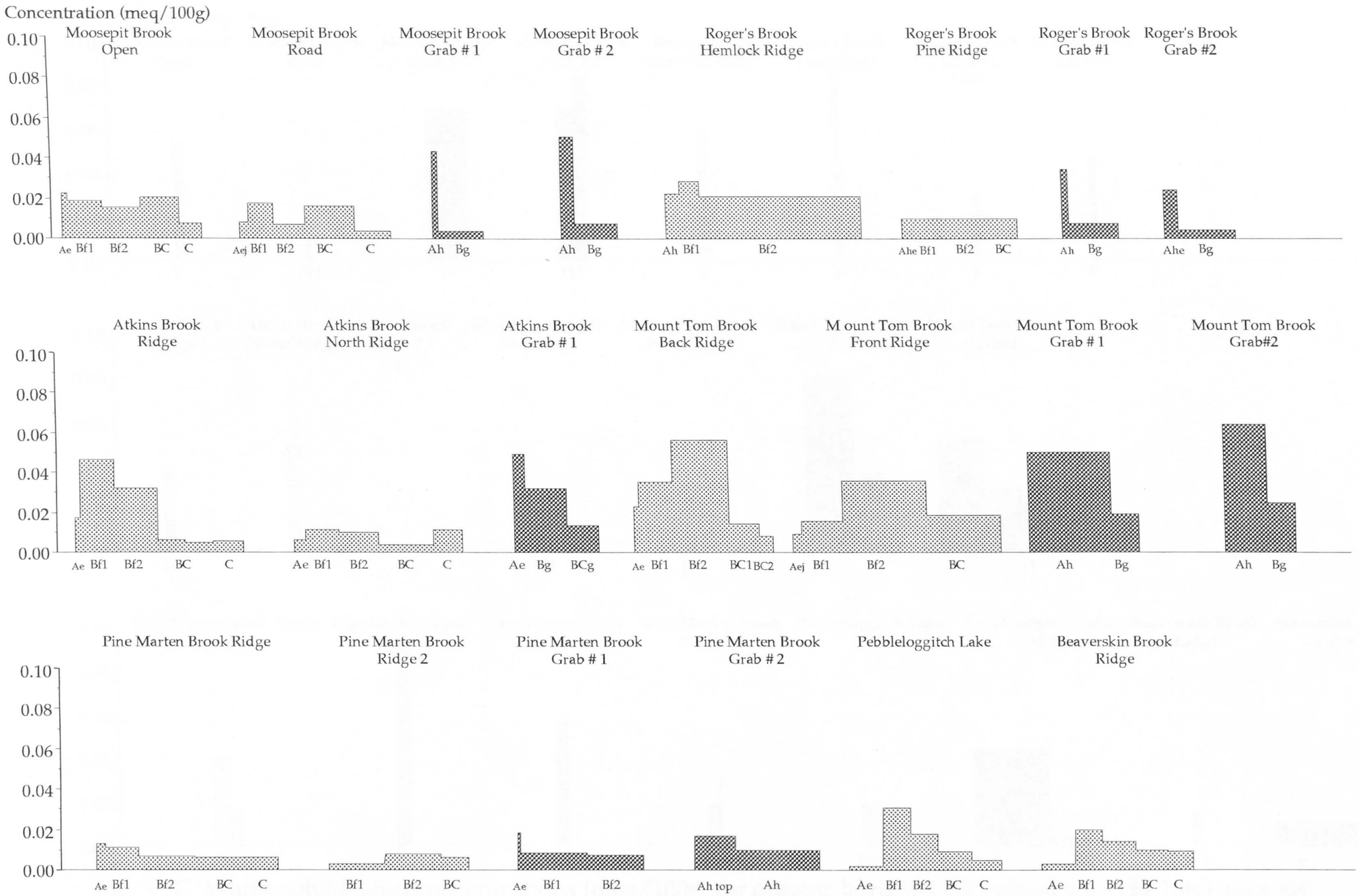


Fig. V F. Water-soluble chlorine concentrations (meq/100g) in mineral soil horizons (▨ upland soils; ▩ lowland soils)

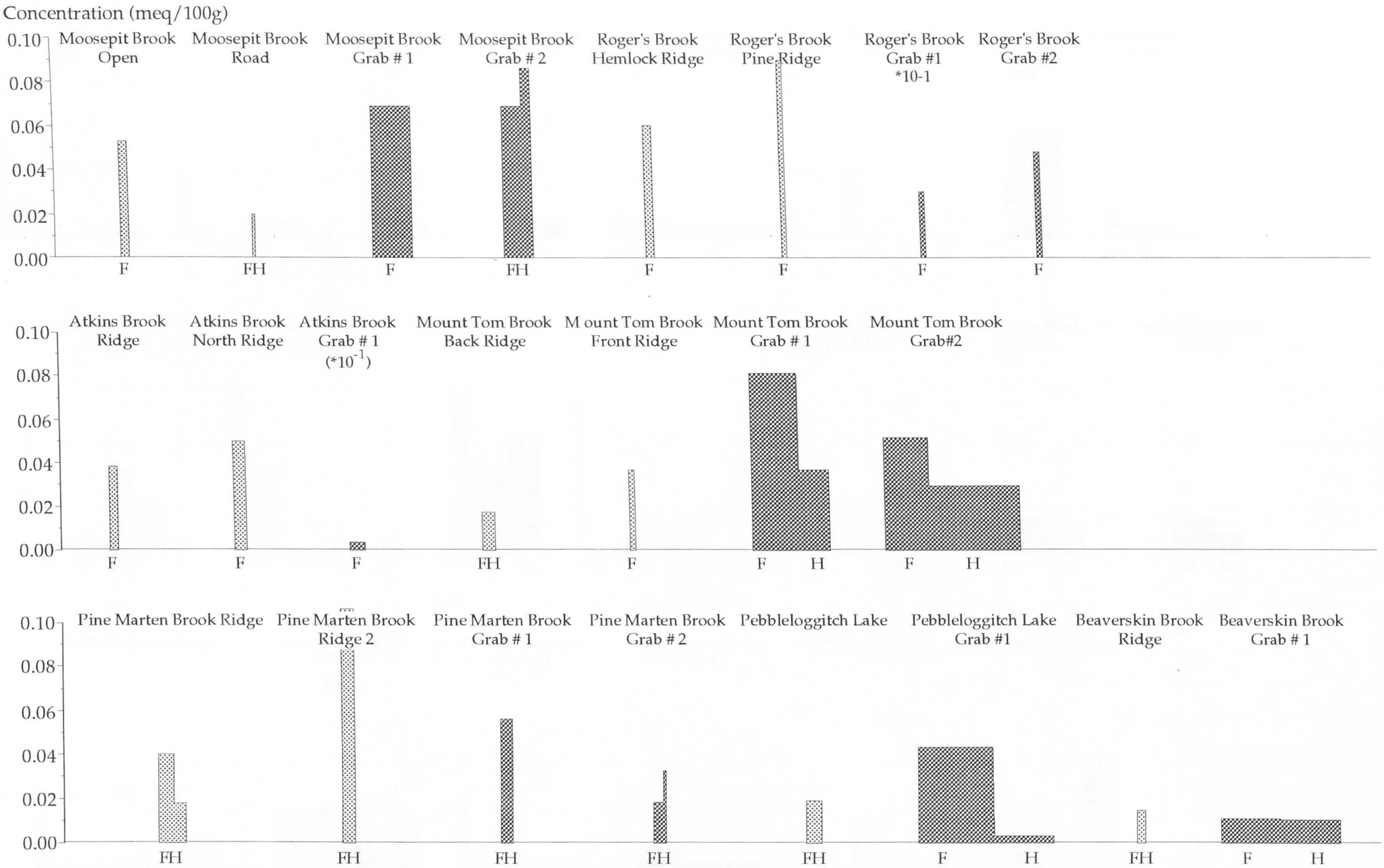
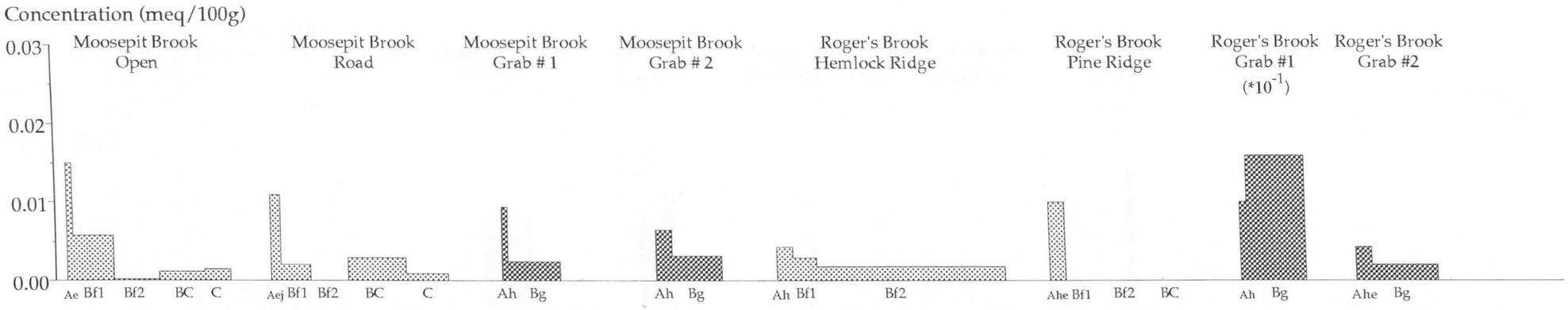
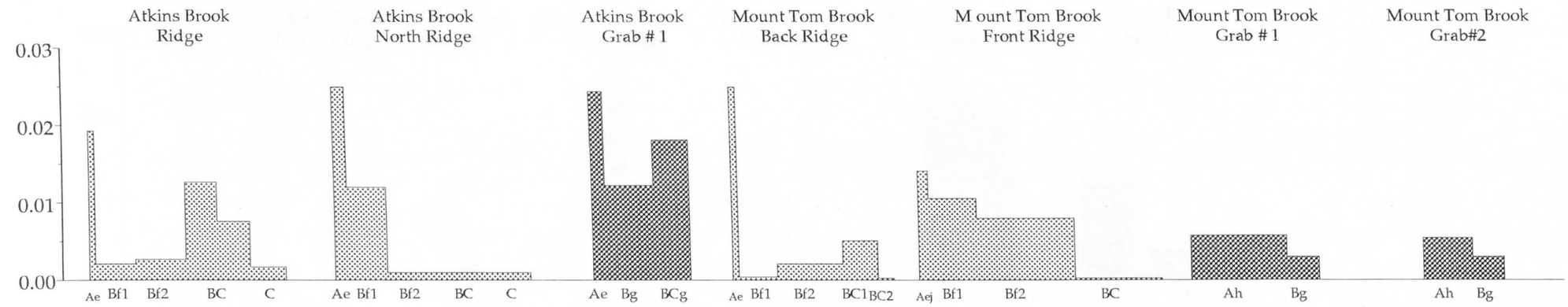


Fig. V G. Water-soluble iron concentrations (meq/100g) for organic horizons (▒ upland soils; ▓ lowland soils).





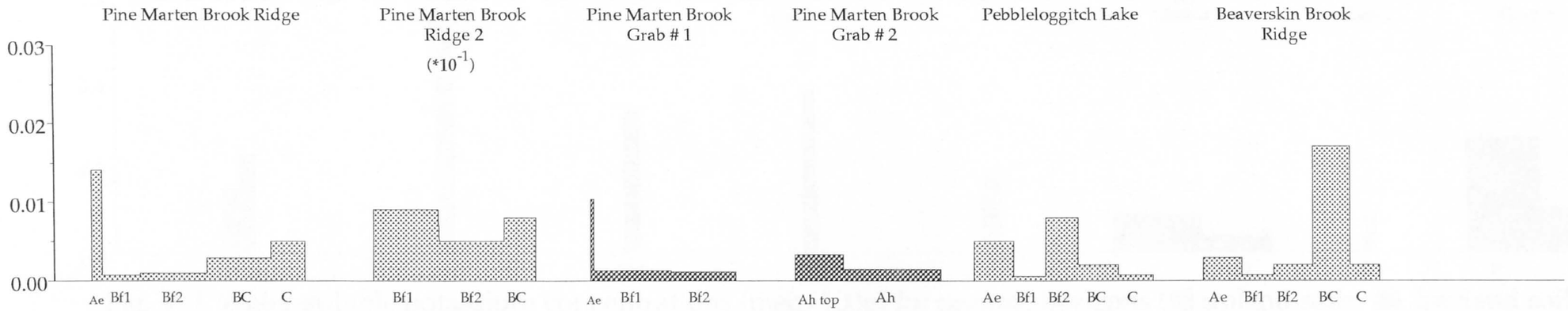


Fig. V H. Water-soluble iron concentrations (meq/100g) in mineral soil horizons (▨ upland soils; ▩ lowland soils)

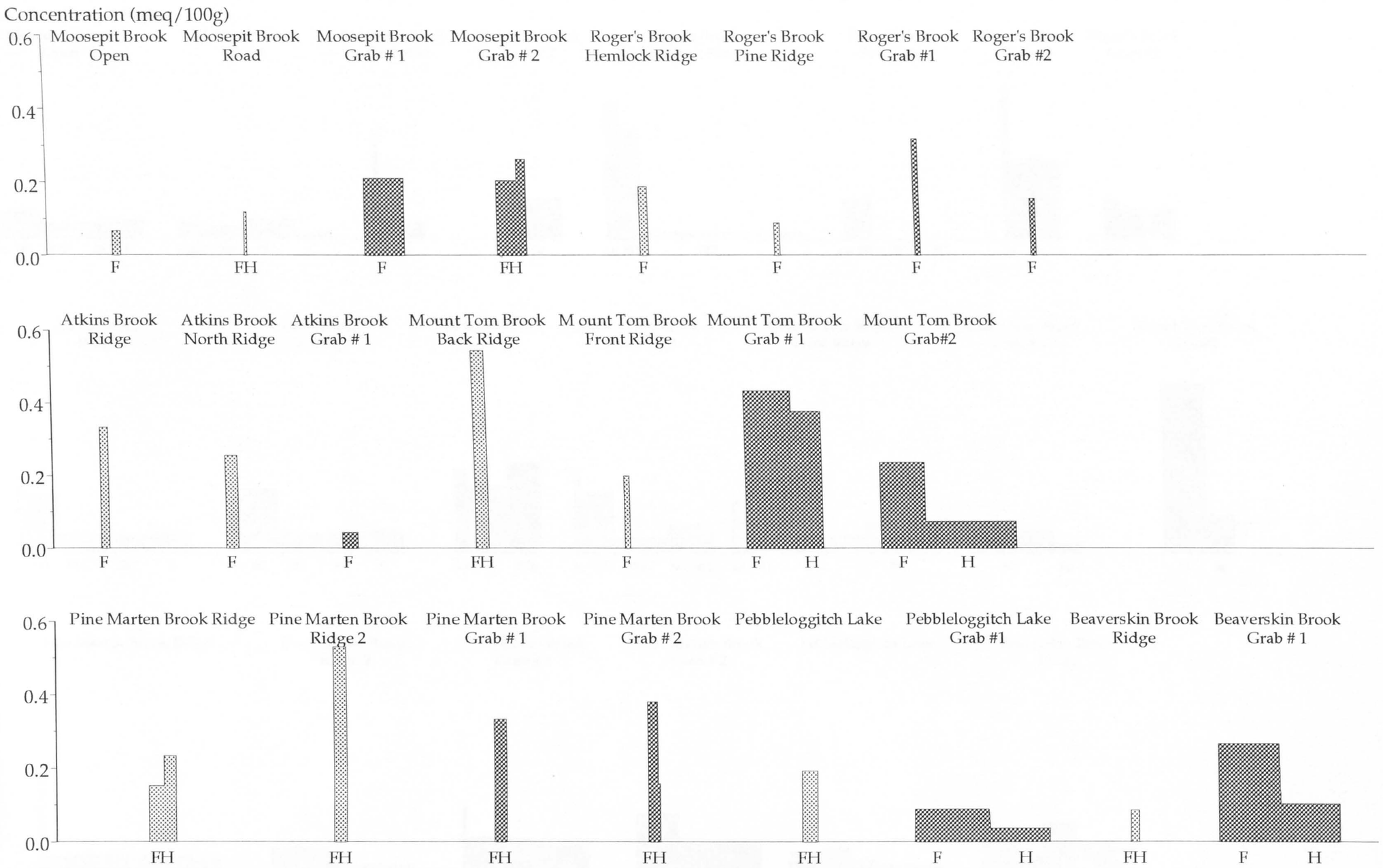
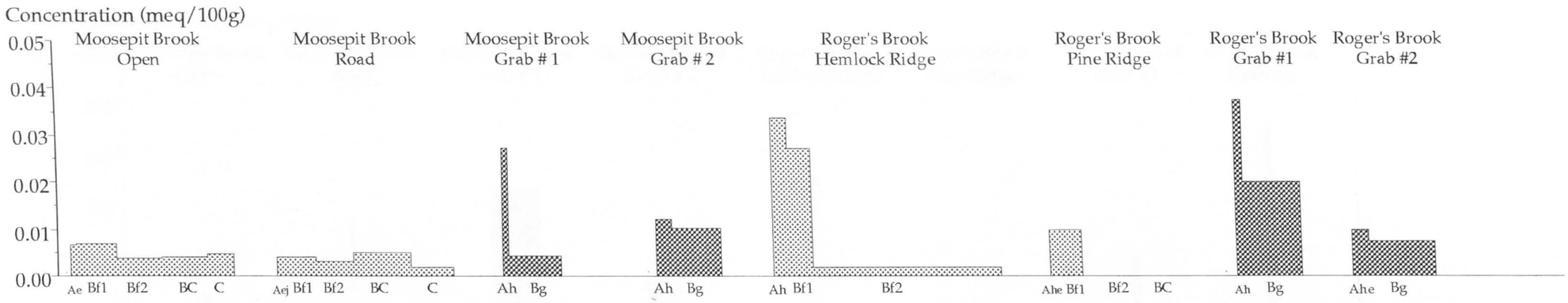
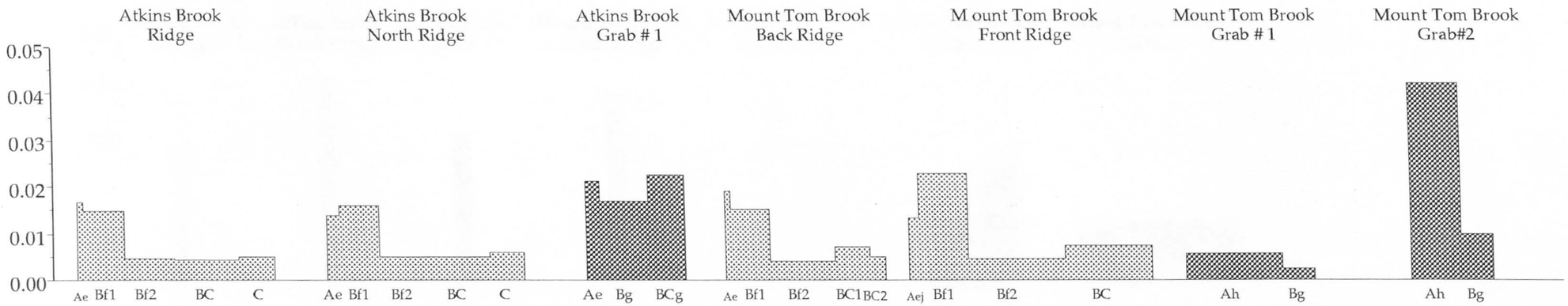


Fig. V I. Water-soluble potassium concentrations (meq/100g) for organic horizons (▨ upland soils; ▩ lowland soils).





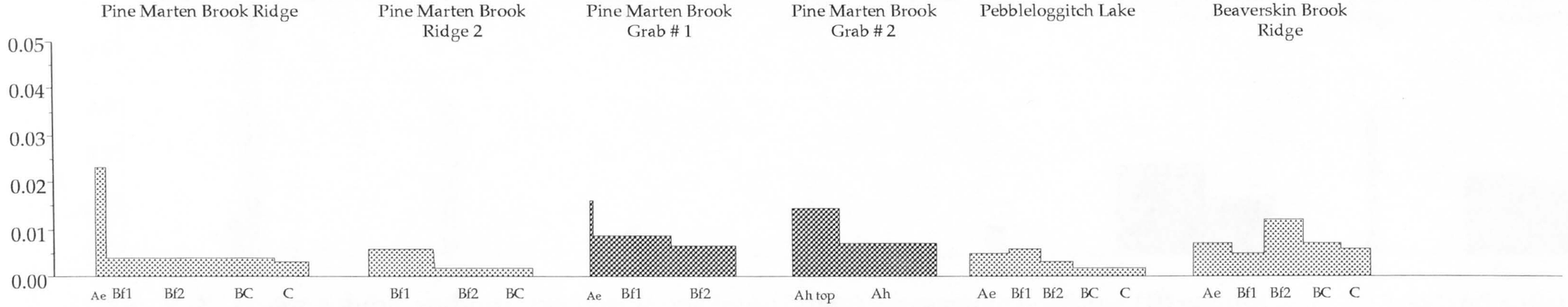


Fig. V J. Water-soluble potassium concentrations (meq/100g) in mineral soil horizons (▨ upland soils; ▩ lowland soils)

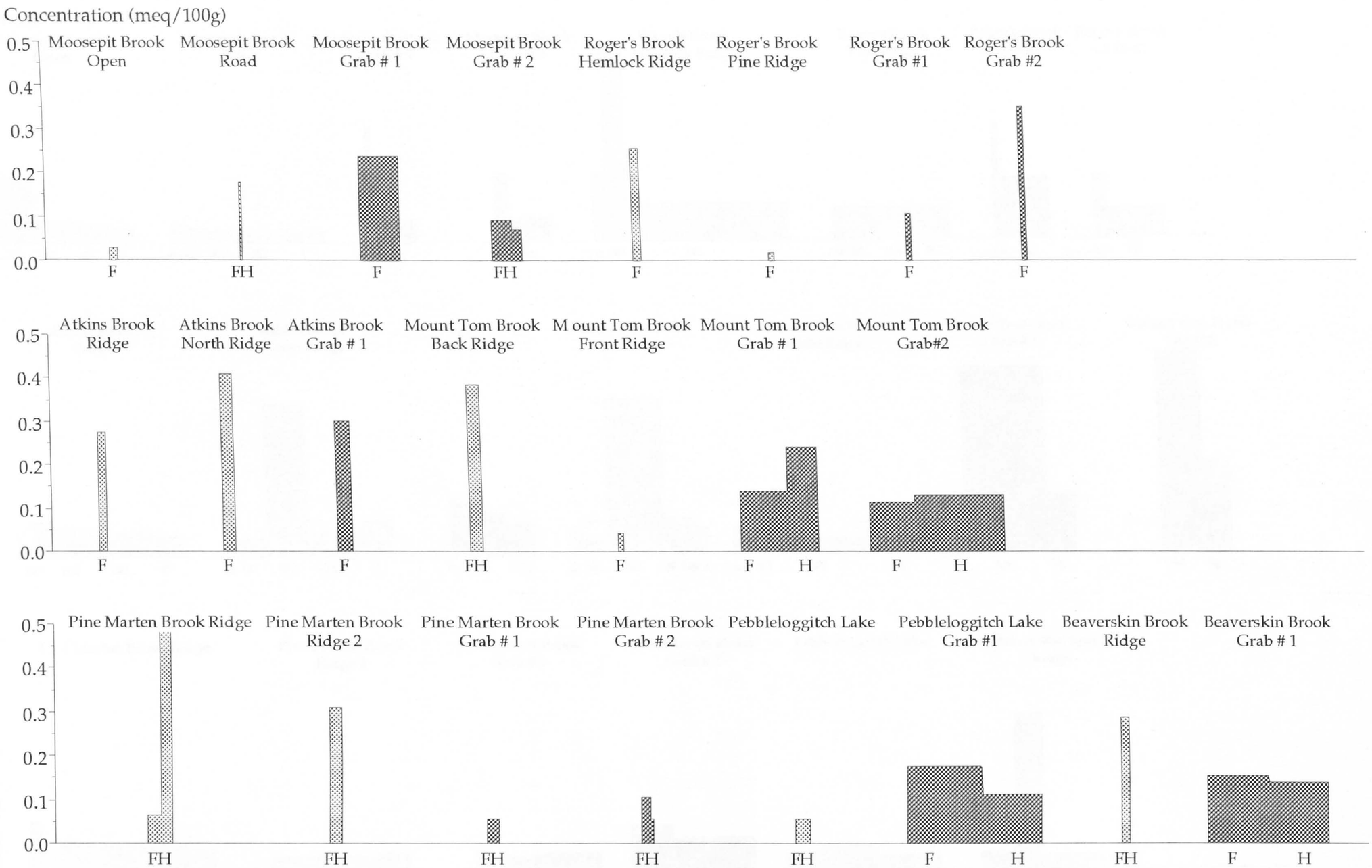
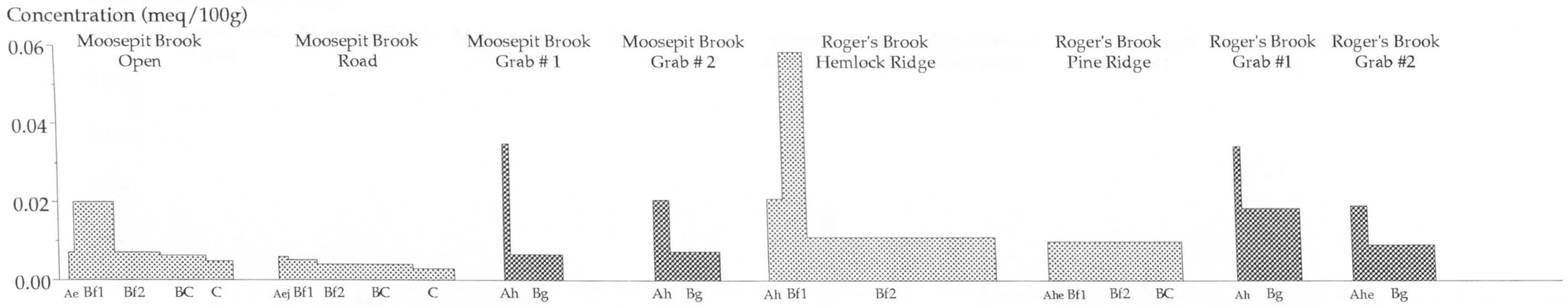
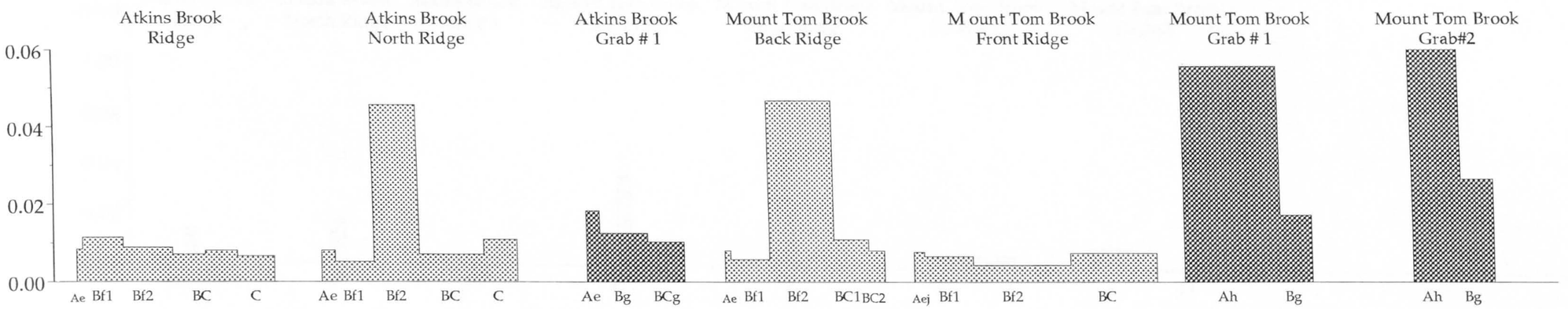


Fig. V K. Water-soluble sodium concentrations (meq/100g) for organic horizons (upland soils; lowland soils).





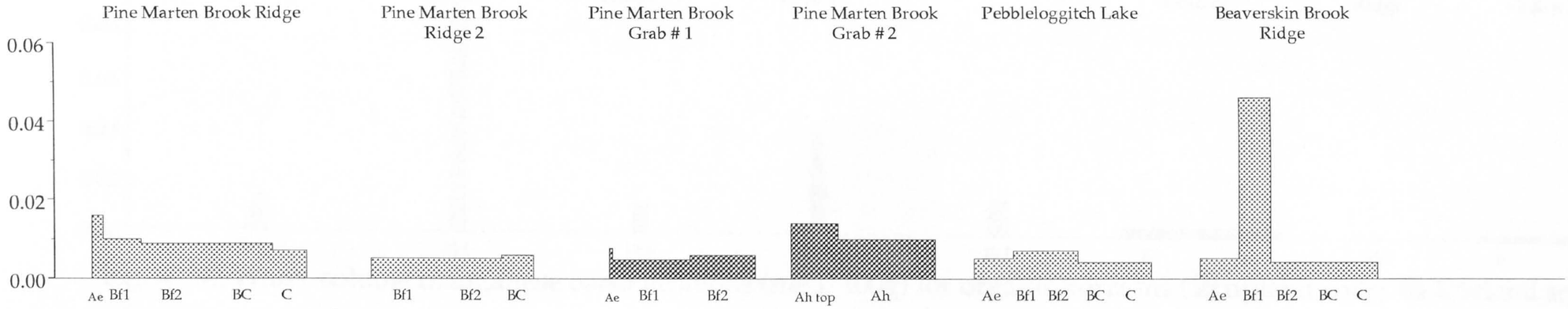


Fig. V L. Water-soluble sodium concentrations (meq/100g) in mineral soil horizons (upland soils; lowland soils)

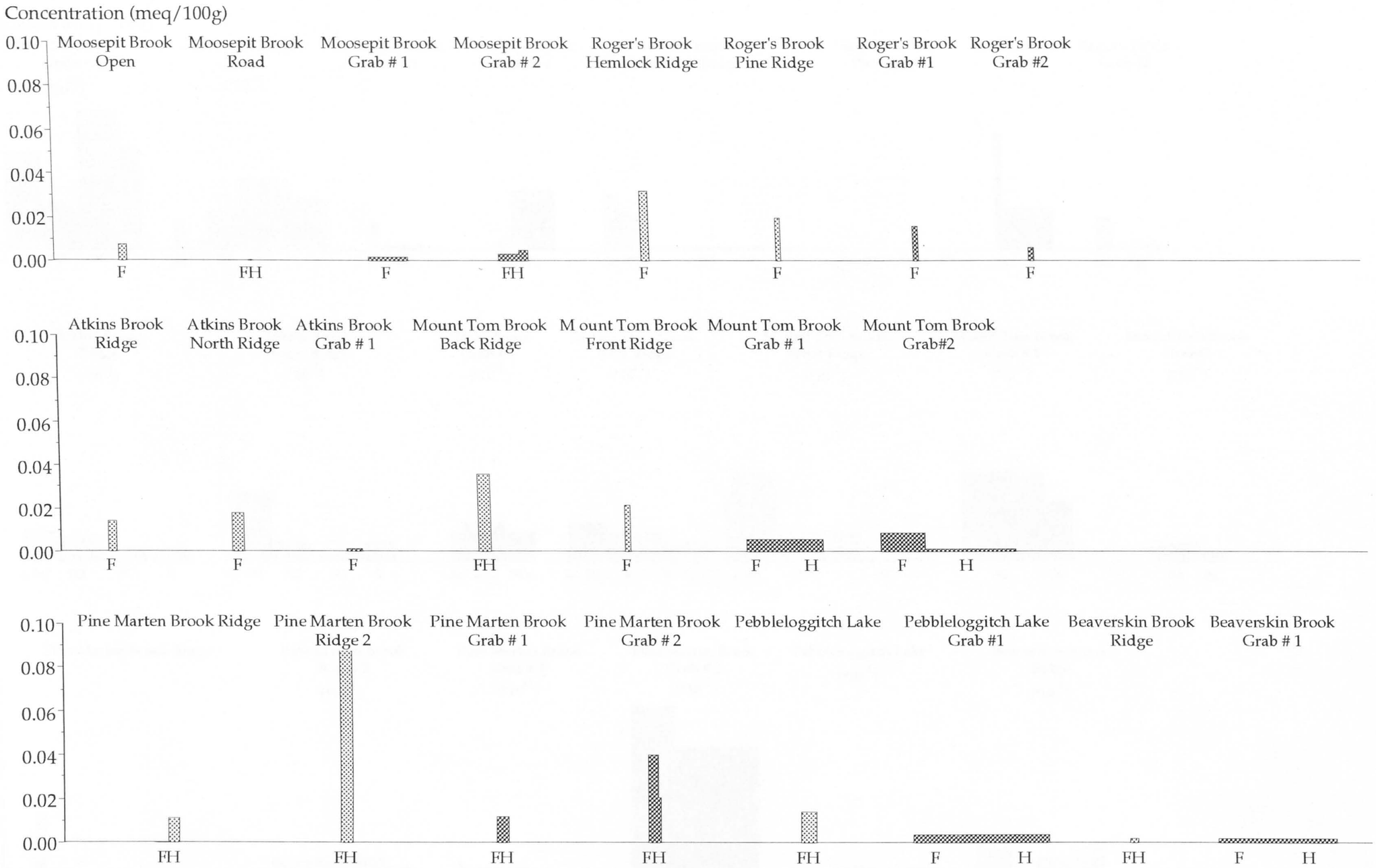
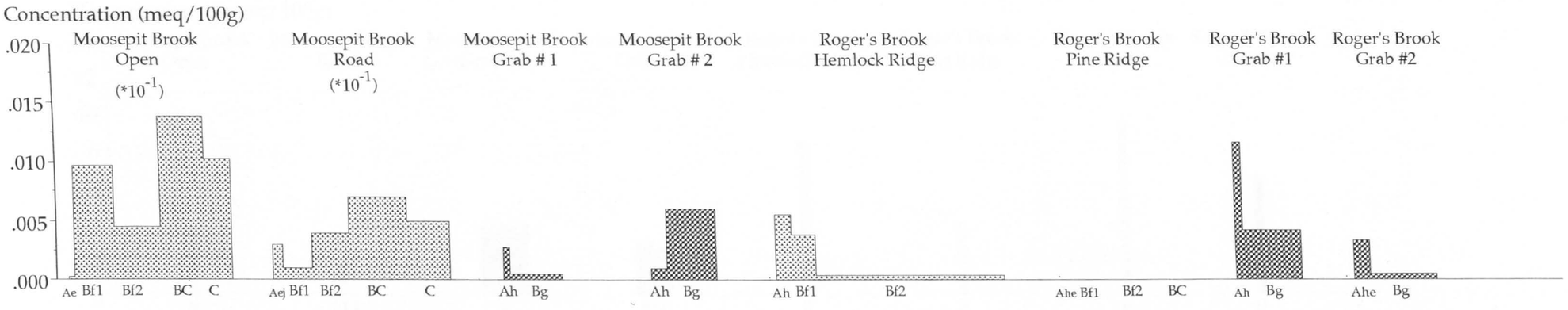
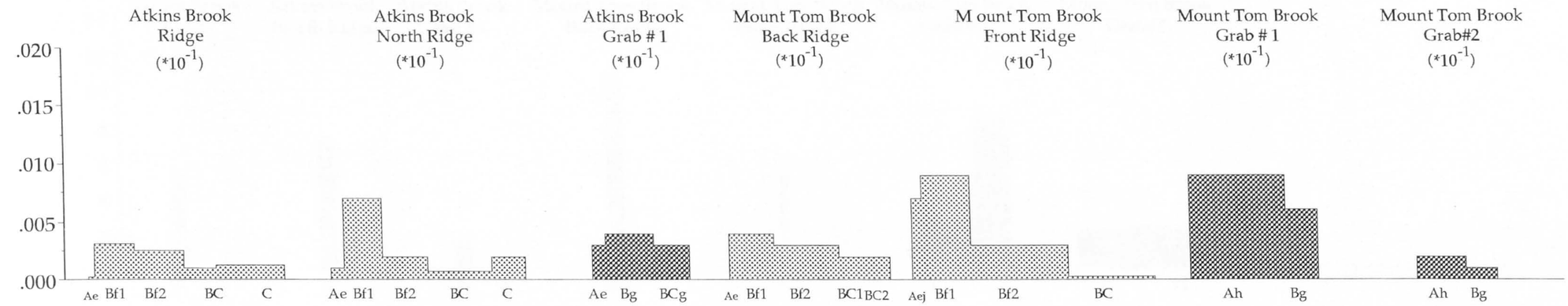


Fig. V M. Water-soluble manganese concentrations (meq/100g) for organic horizons (upland soils; lowland soils).





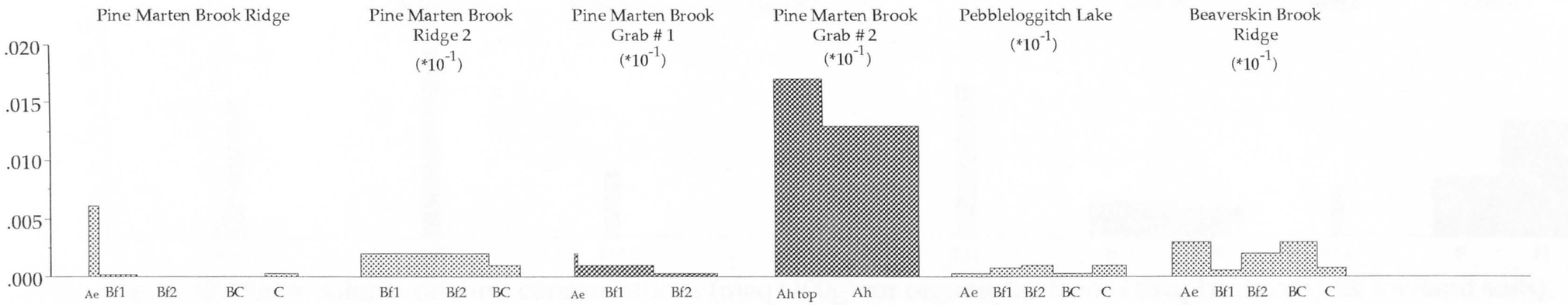


Fig. V N. Water-soluble manganese concentrations (meq/100g) for mineral soil horizons (▨ upland soils; ▩ lowland soils)

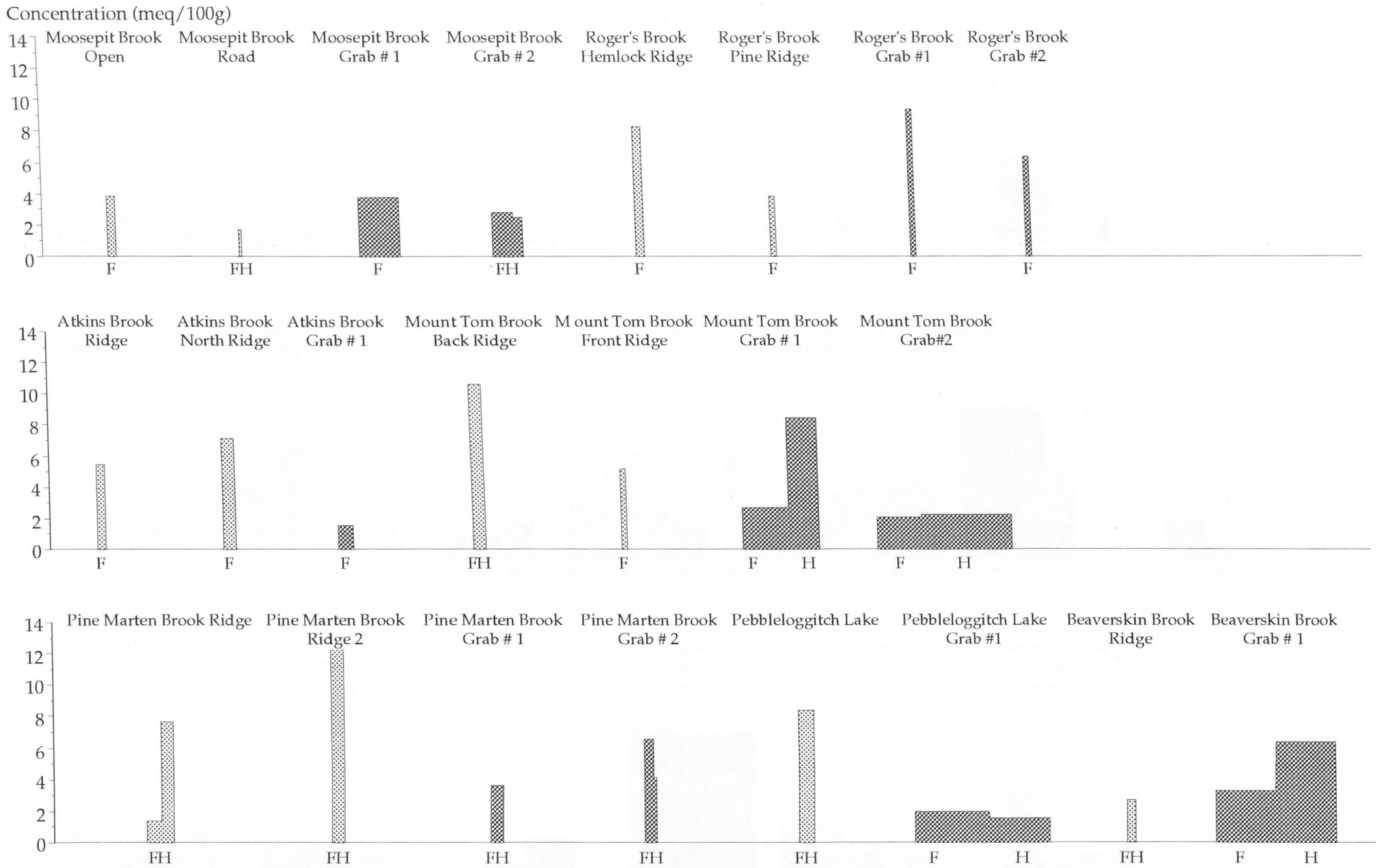
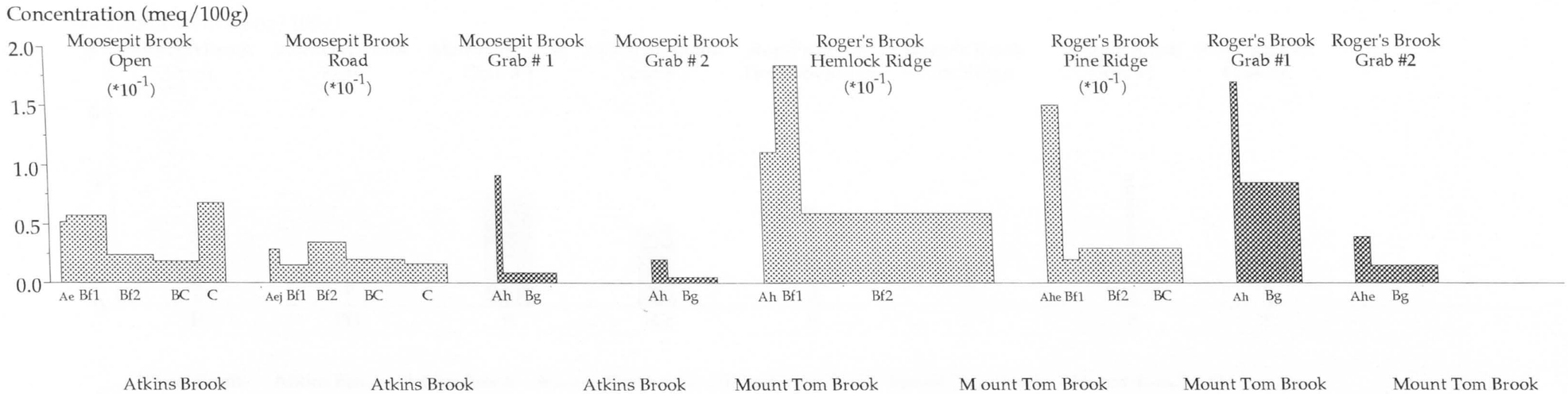
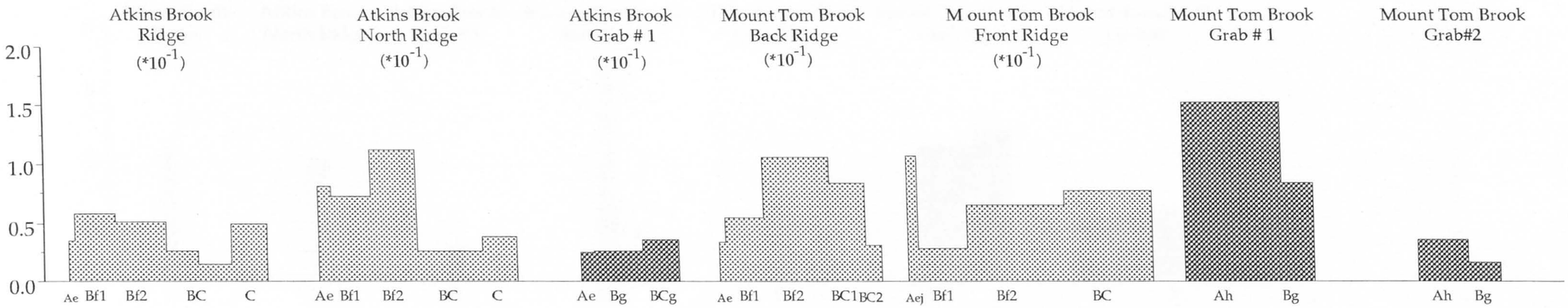


Fig. V O. Water-soluble calcium concentrations (meq/100g) for organic horizons (upland soils; lowland soils).





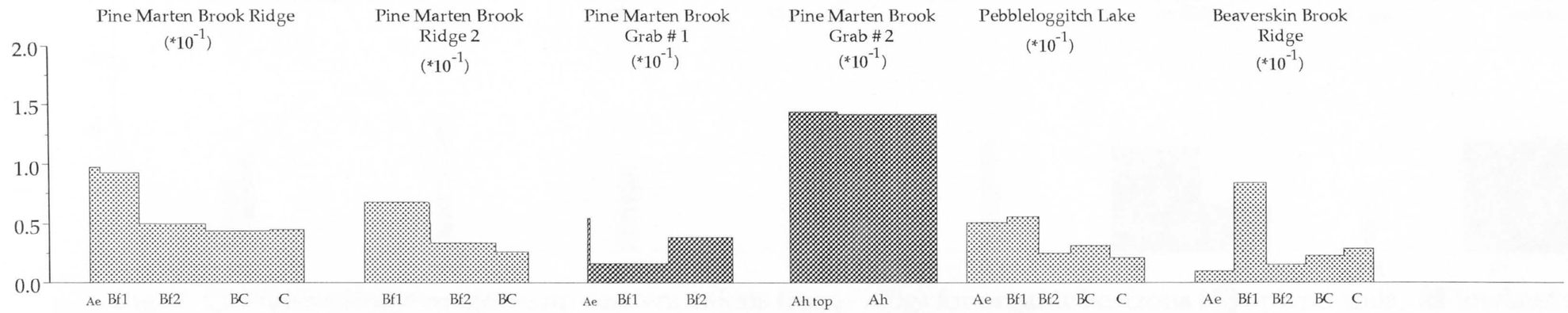


Fig. V P. Water-soluble calcium concentrations (meq/100g) for mineral soil horizons (▨ upland soils; ▩ lowland soils)

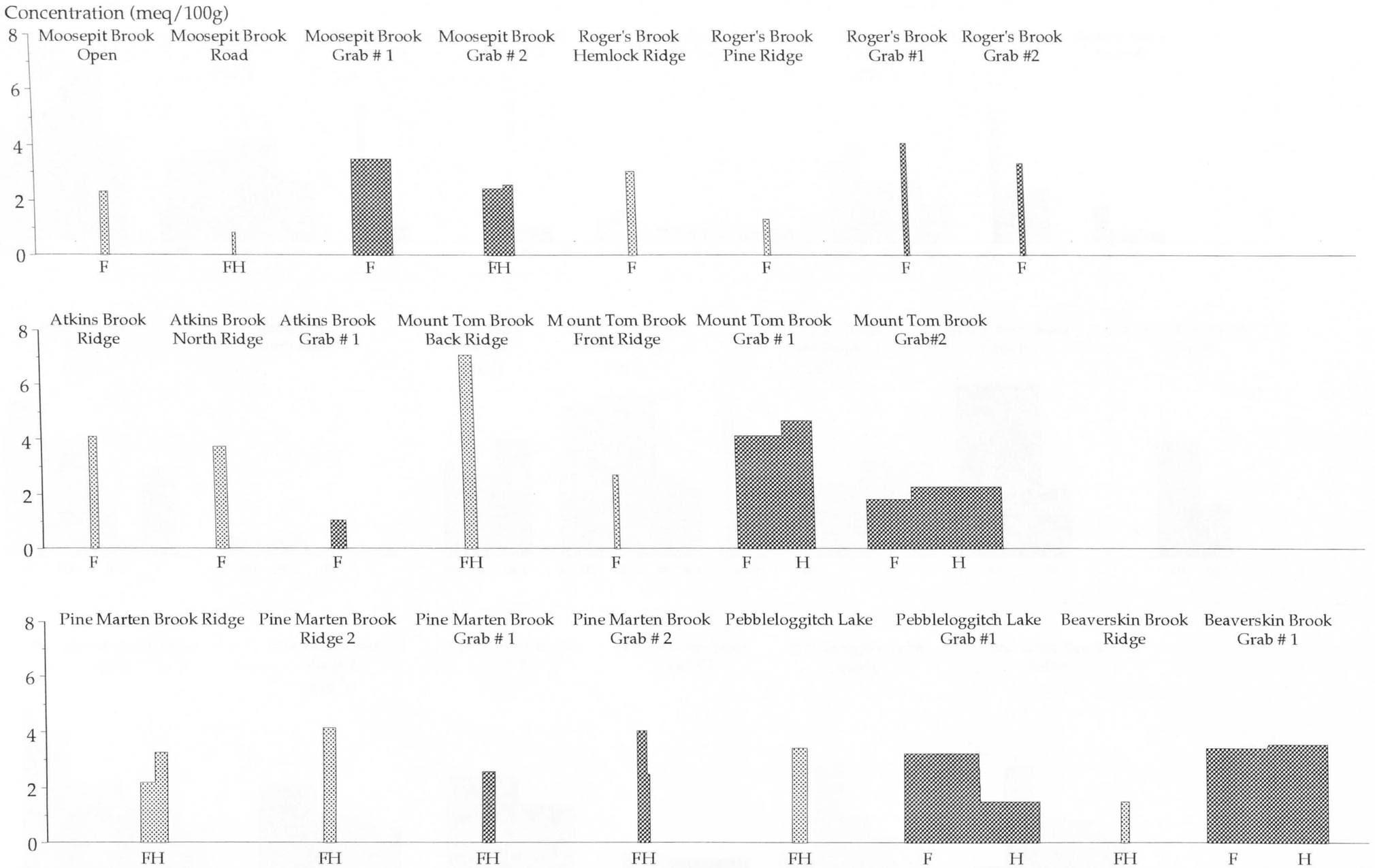


Fig. V Q. Water-soluble magnesium concentrations (meq/100g) for organic horizons (upland soils; lowland soils).

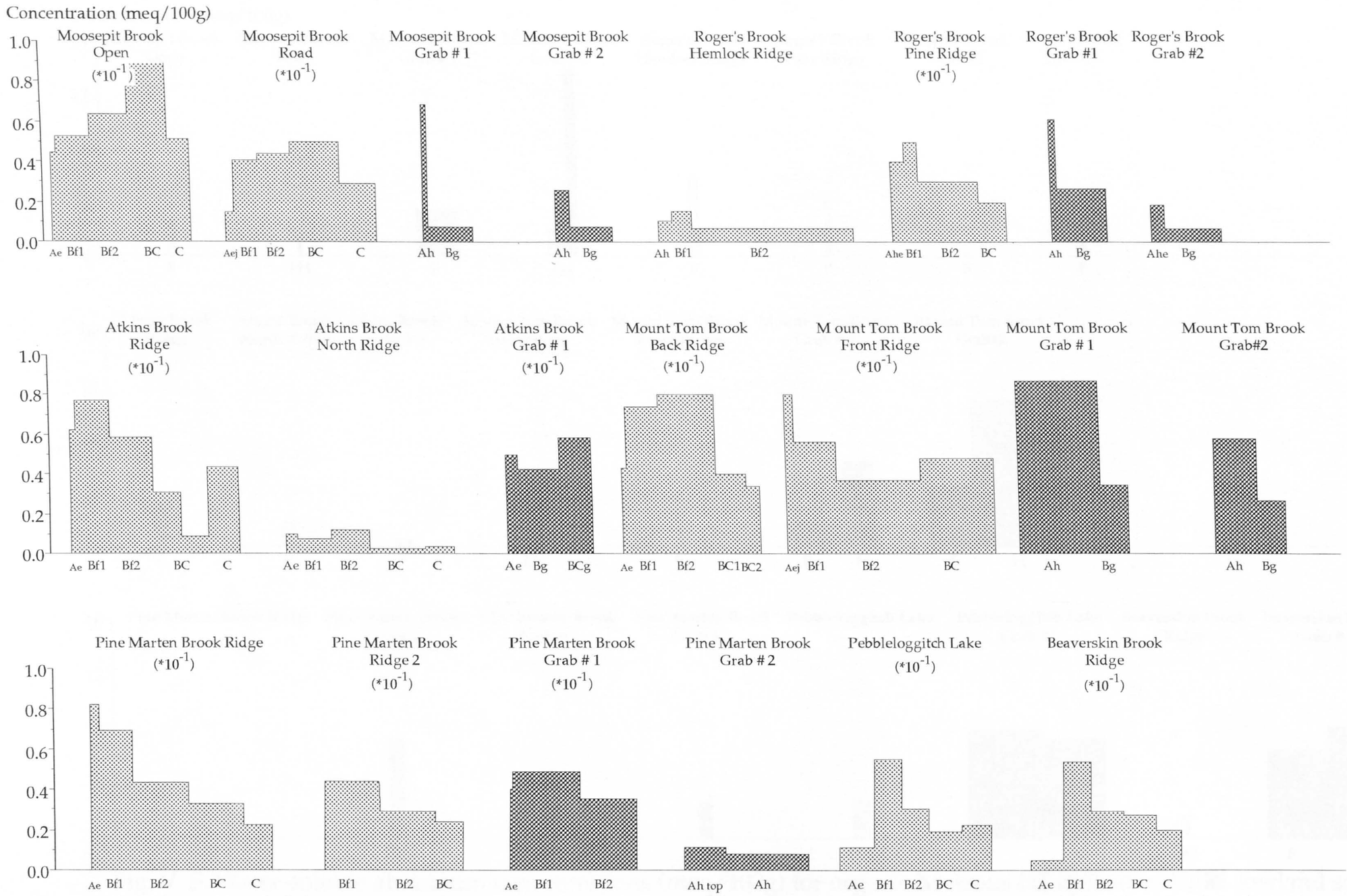


Fig. V R. Water-soluble magnesium concentrations (meq/100g) for mineral soil horizons (▨ upland soils; ▩ lowland soils)

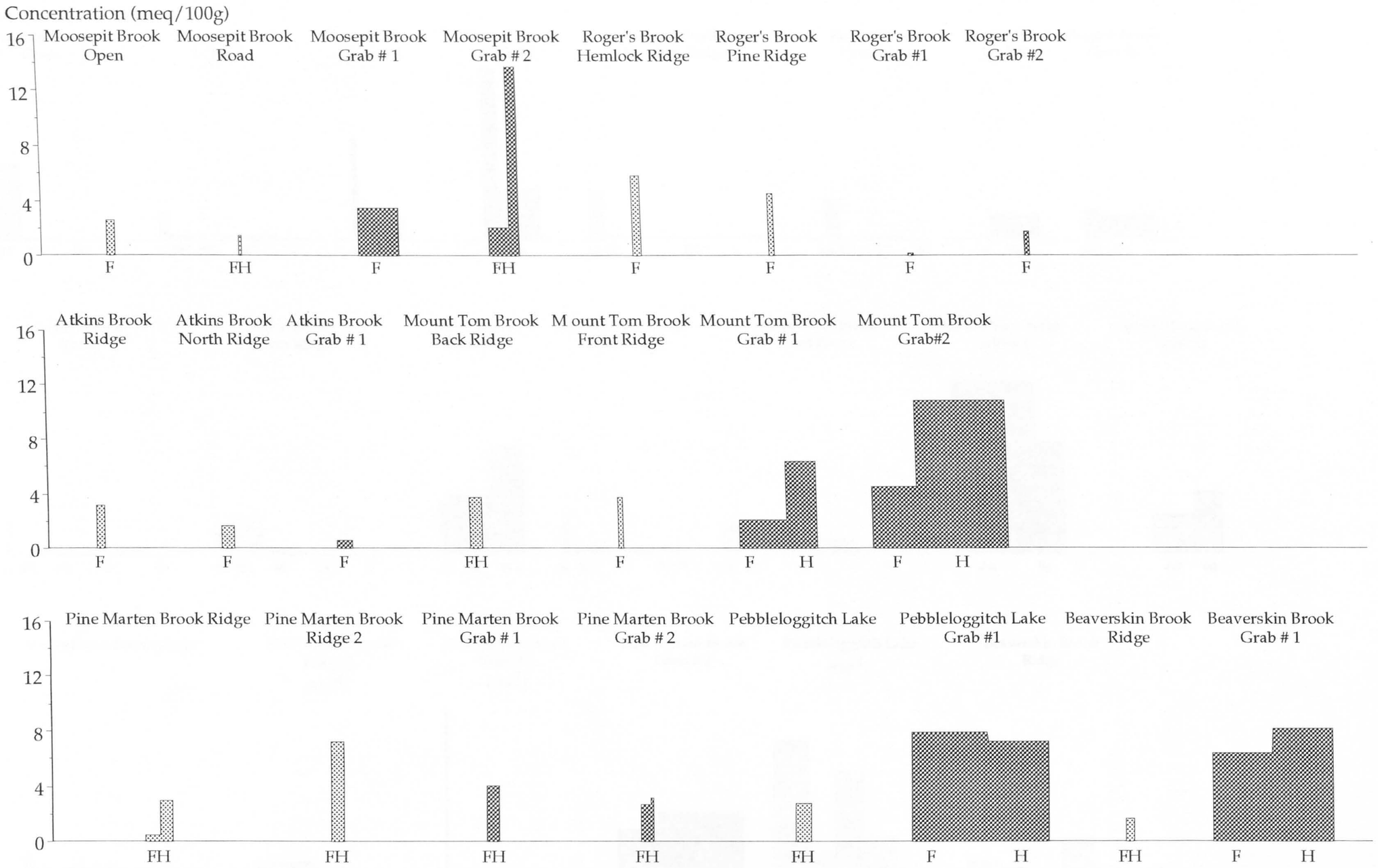
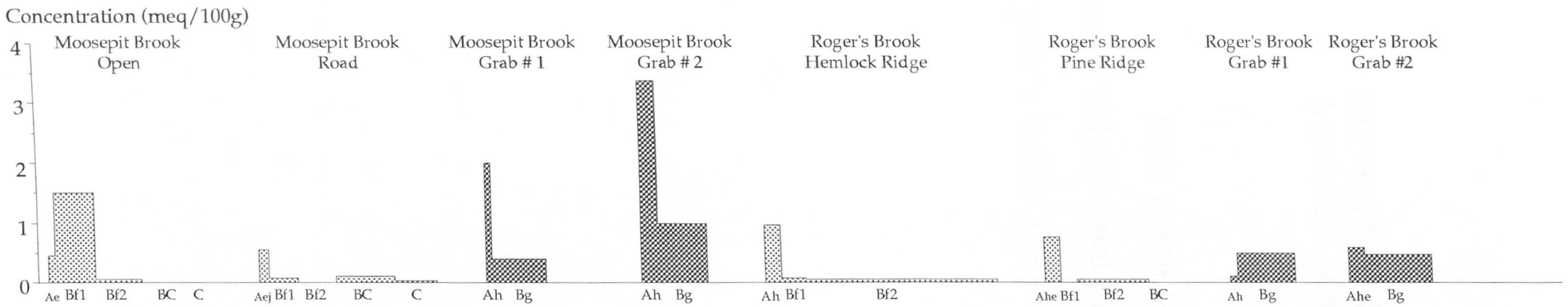
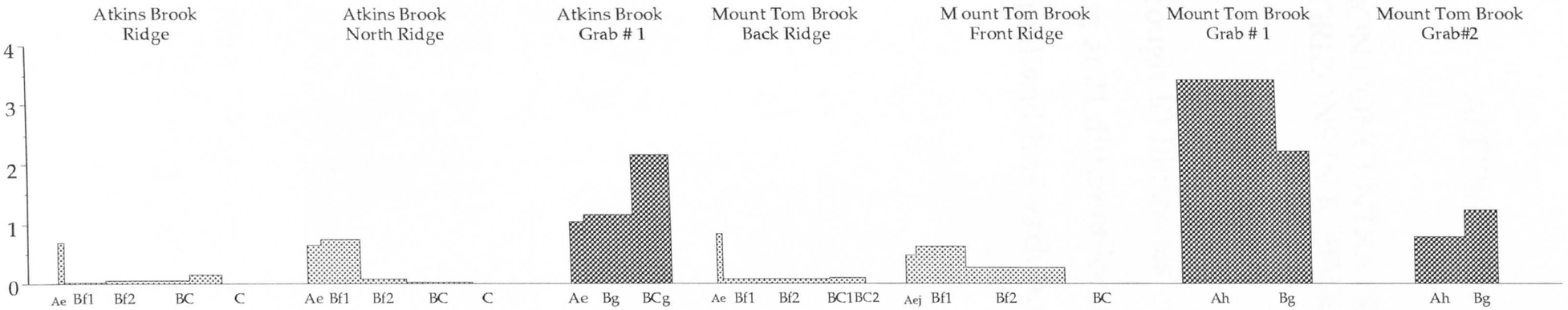


Fig. V S. Water-soluble aluminum concentrations (meq/100g) for organic horizons (upland soils; lowland soils).





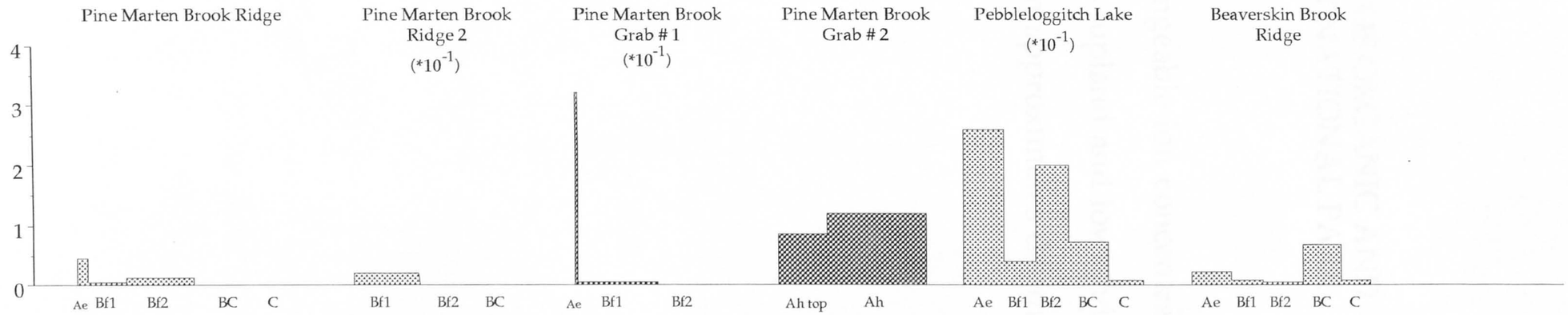


Fig. V T. Water-soluble aluminum concentrations (meq/100g) for mineral soil horizons (▨ upland soils; ▩ lowland soils)

APPENDIX VI

EXCHANGEABLE ION CONCENTRATIONS OF ORGANIC AND MINERAL SOIL HORIZONS IN KEJIMKUJIK NATIONAL PARK

Each graph (A through R) illustrates exchangeable ion concentrations (meq/100g) for soil pits dug at 21 different locations [upland and lowland (or "grab") soils]. The horizontal width of each horizon approximates depth.

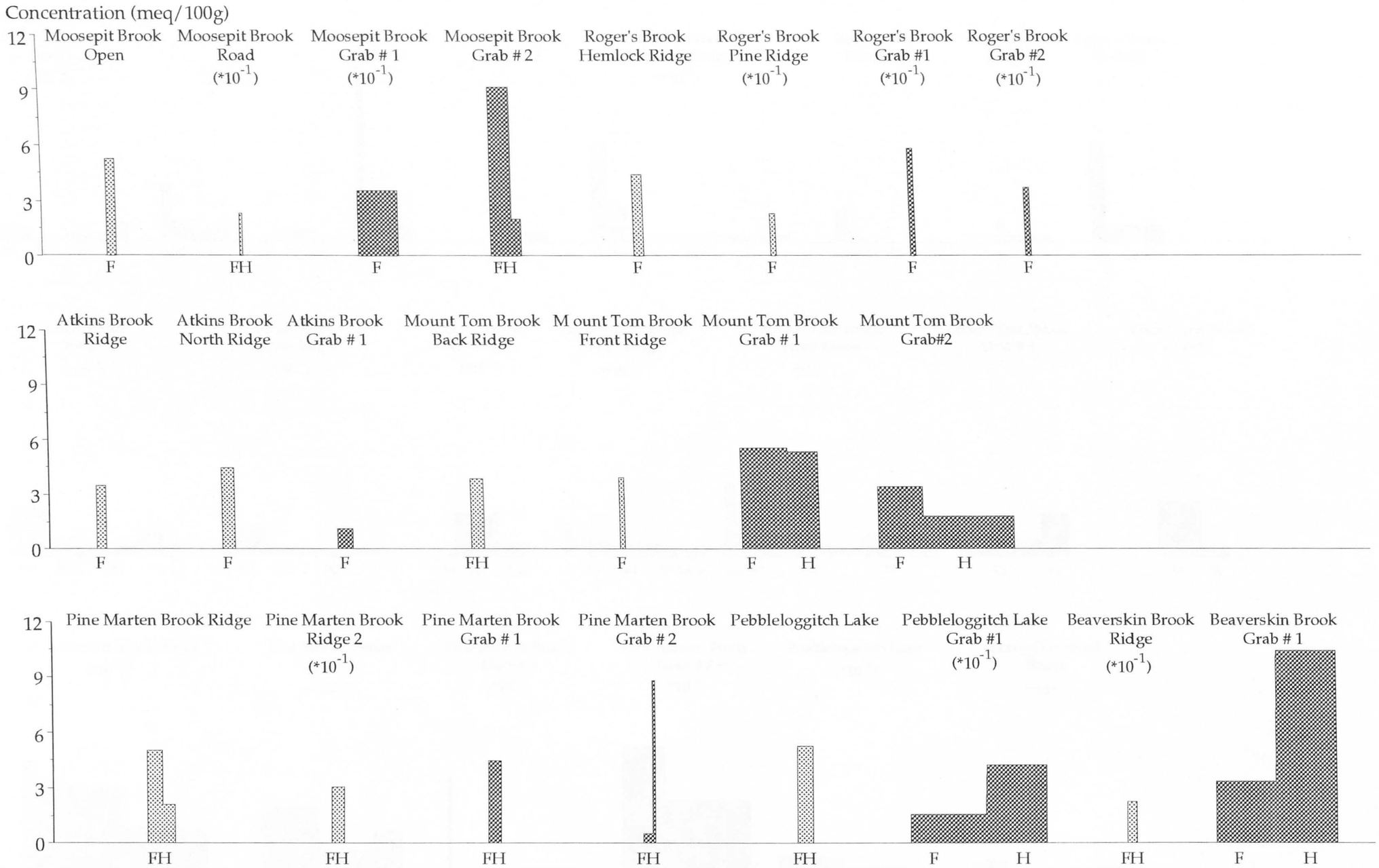


Fig. VI A. Exchangeable calcium concentrations (meq/100g) for organic horizons (upland soils; lowland soils).

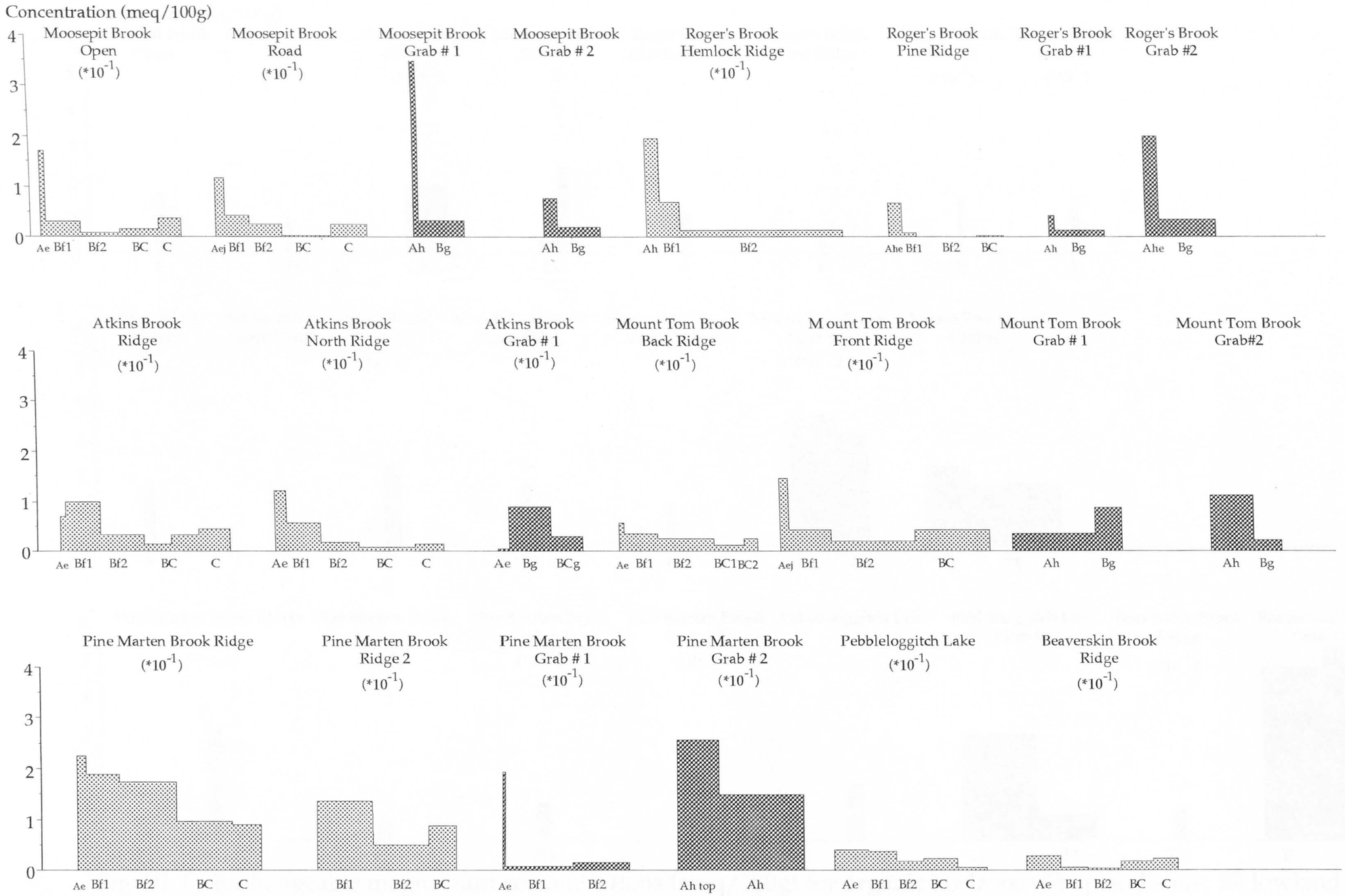


Fig. VI B. Exchangeable calcium concentrations (meq/100g) for mineral soil horizons (▨ upland soils; ▩ lowland soils).

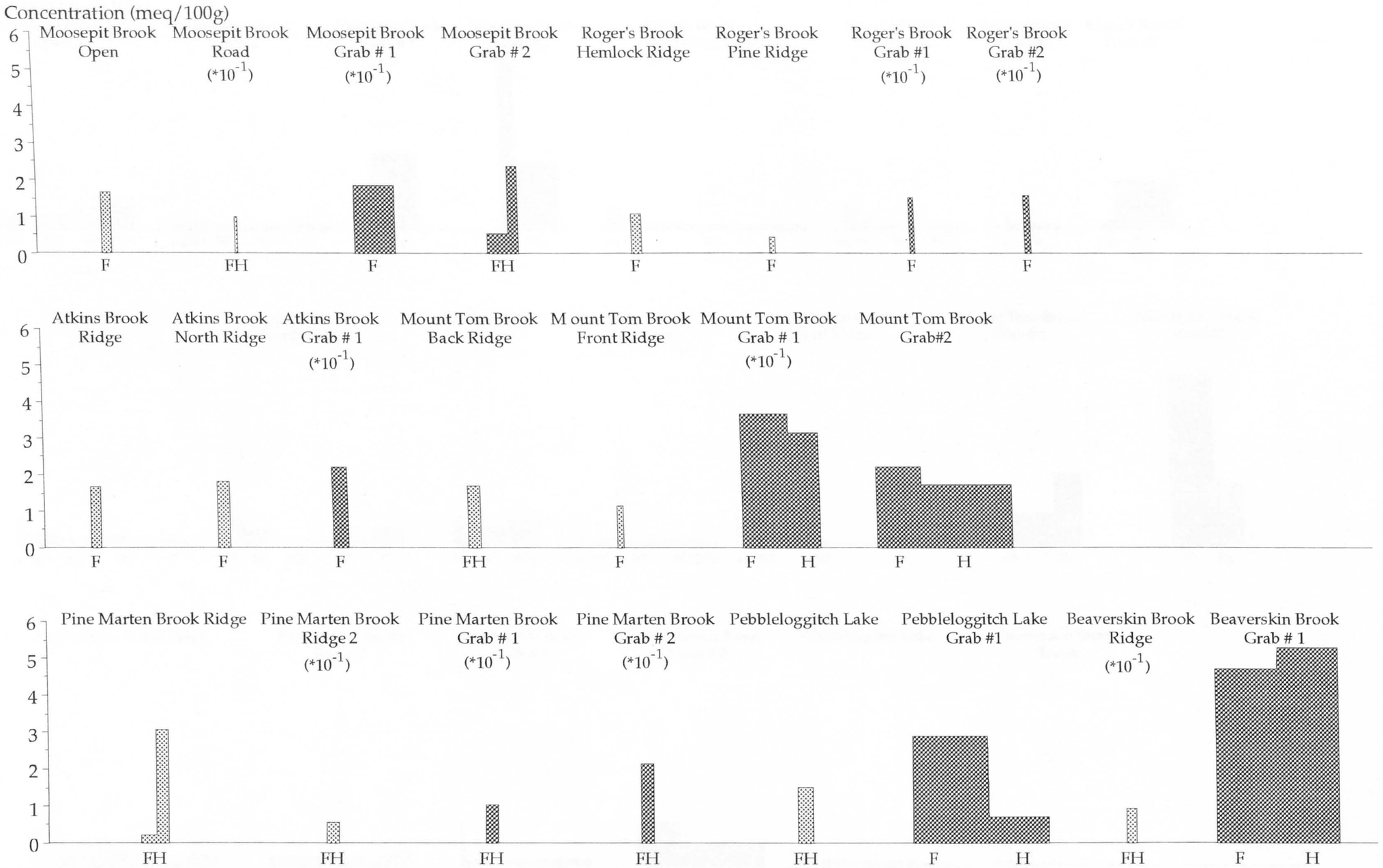


Fig. VI C. Exchangeable magnesium concentrations (meq/100g) for organic horizons (upland soils; lowland soils).

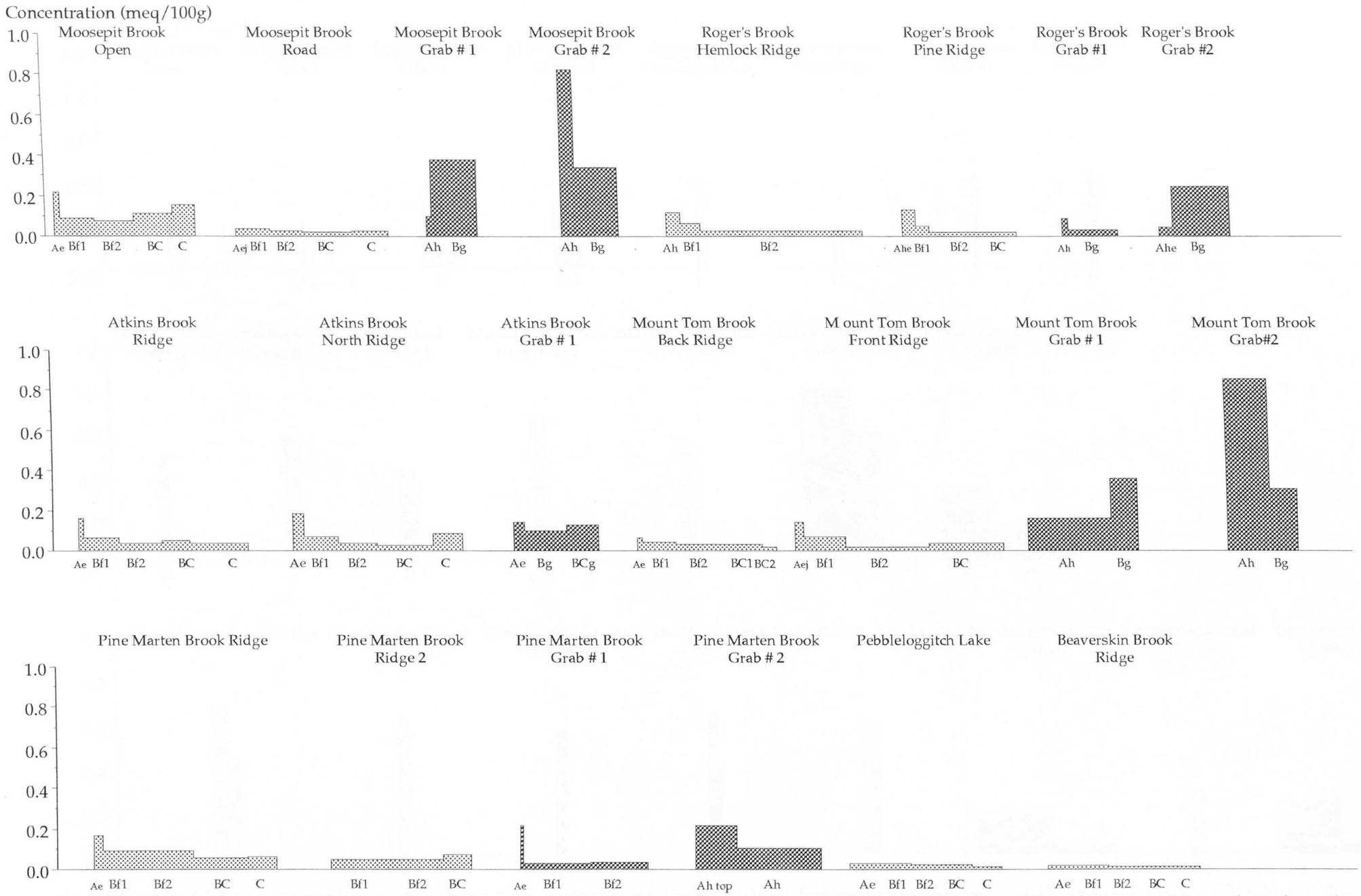


Fig. VI D. Exchangeable magnesium concentrations (meq/100g) for mineral soil horizons (▒ upland soils; ▩ lowland soils).

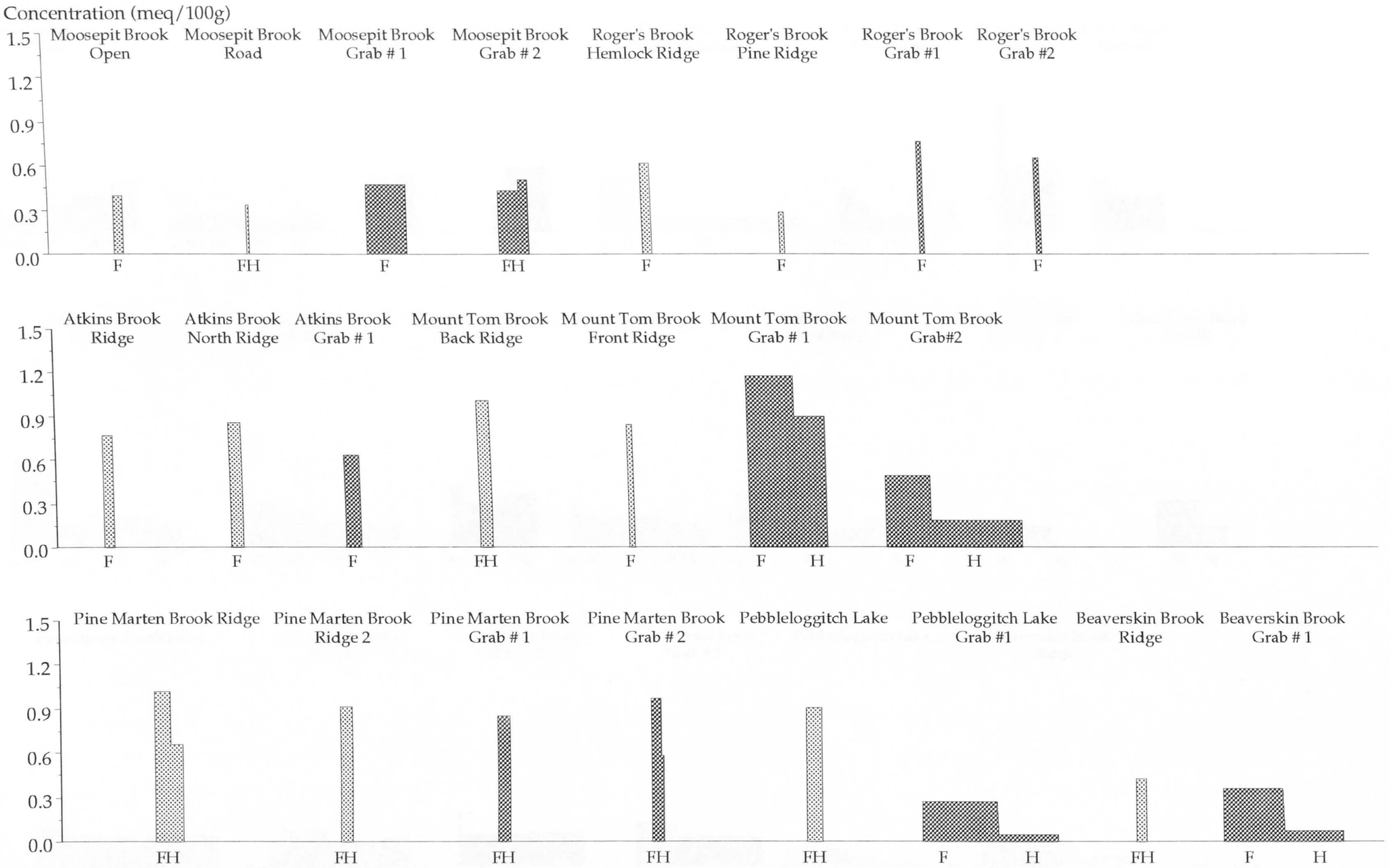


Fig. VI E. Exchangeable potassium concentrations (meq/100g) for organic horizons (upland soils; lowland soils).

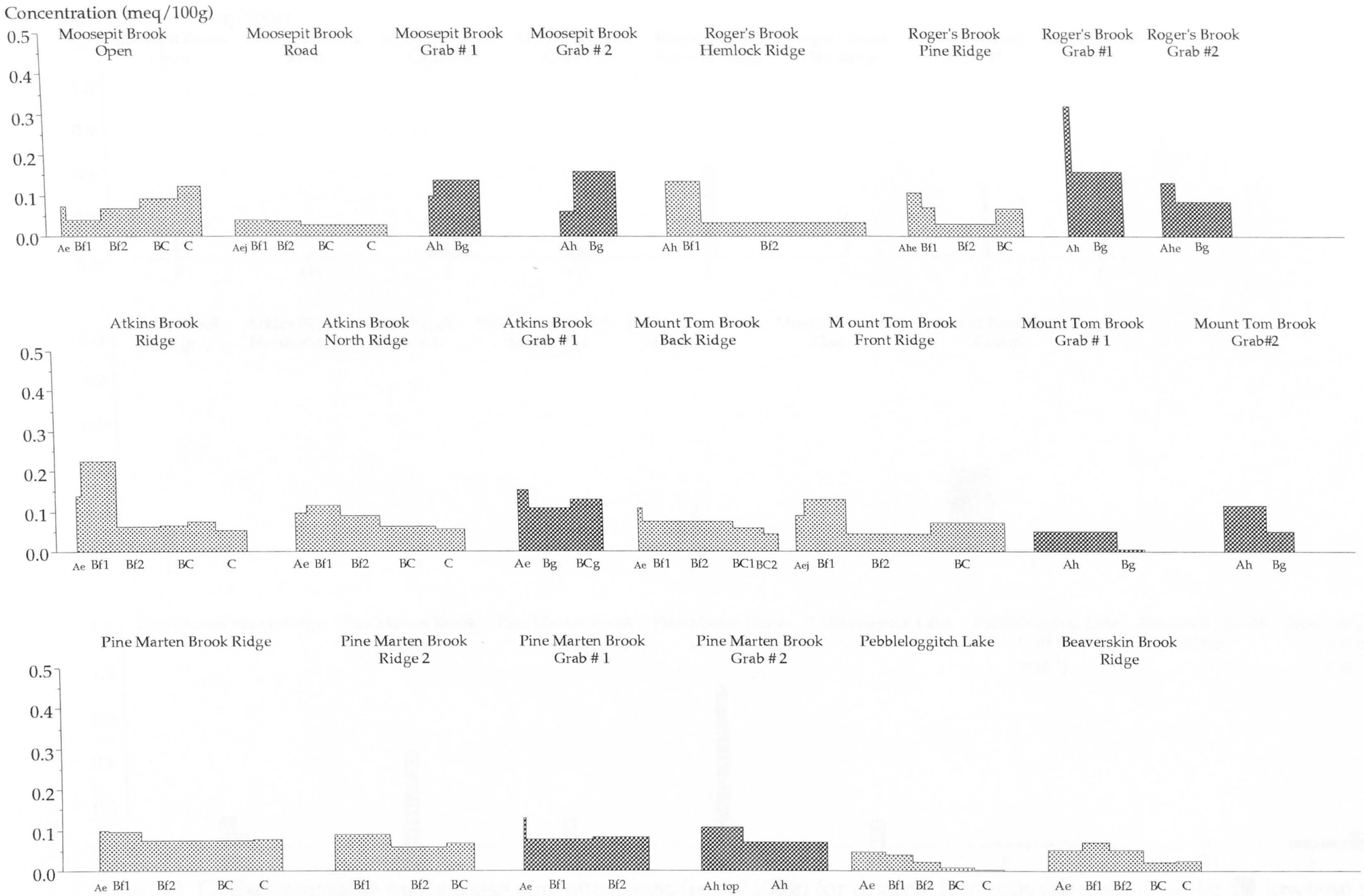
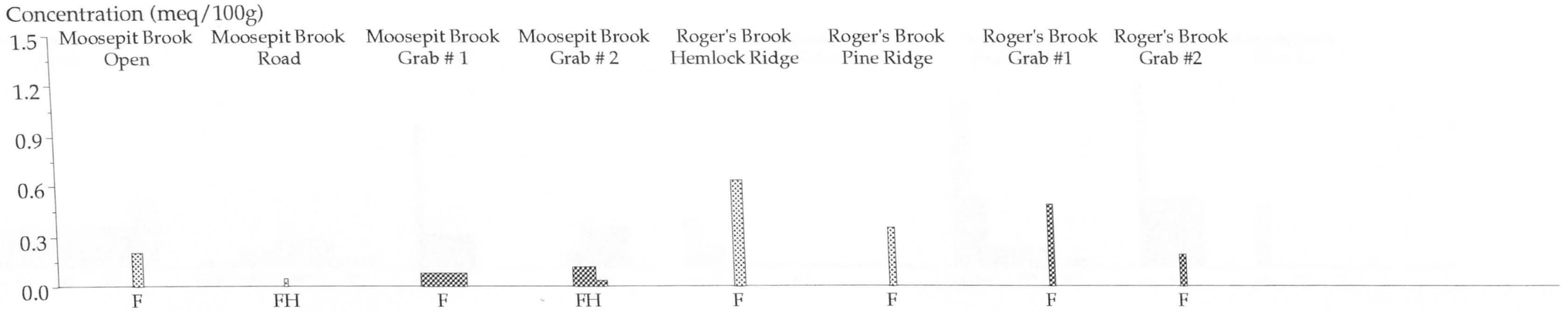
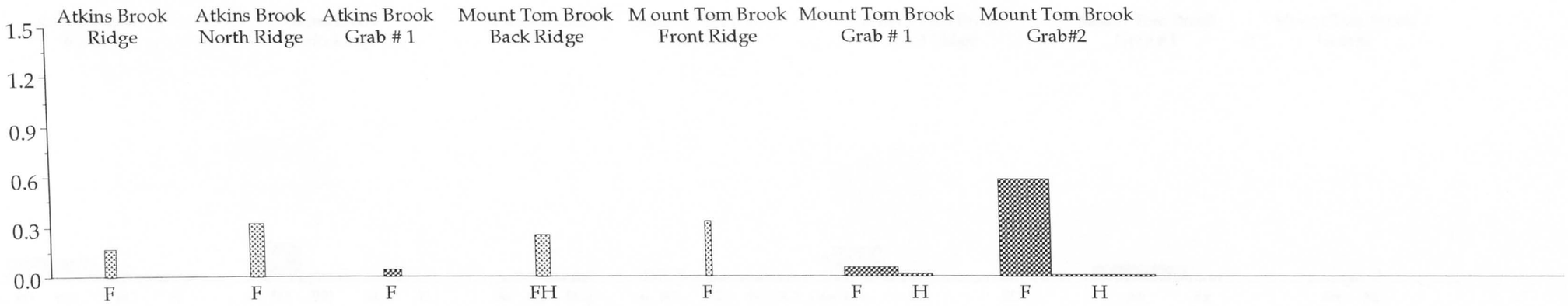


Fig. VI F. Exchangeable potassium concentrations (meq/100g) for mineral soil horizons (upland soils; lowland soils).





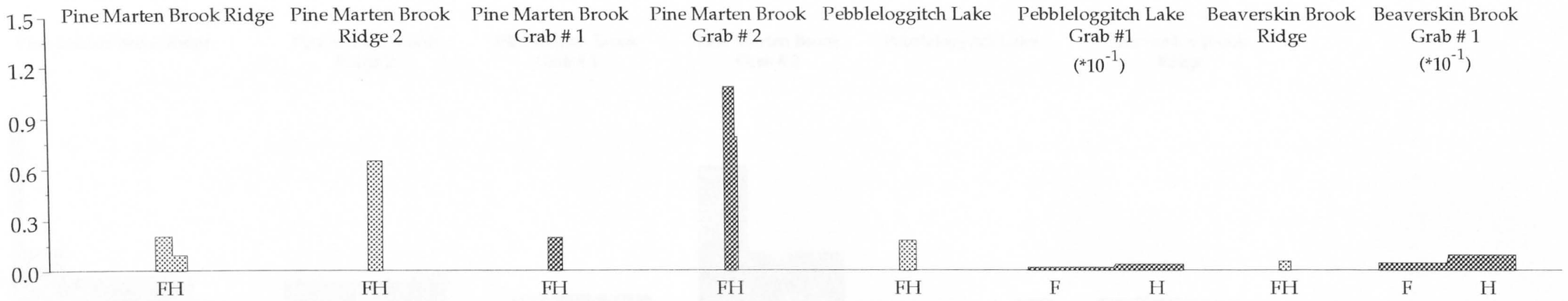


Fig. VI G. Exchangeable manganese concentrations (meq/100g) for organic horizons (▨ upland soils; ▩ lowland soils).

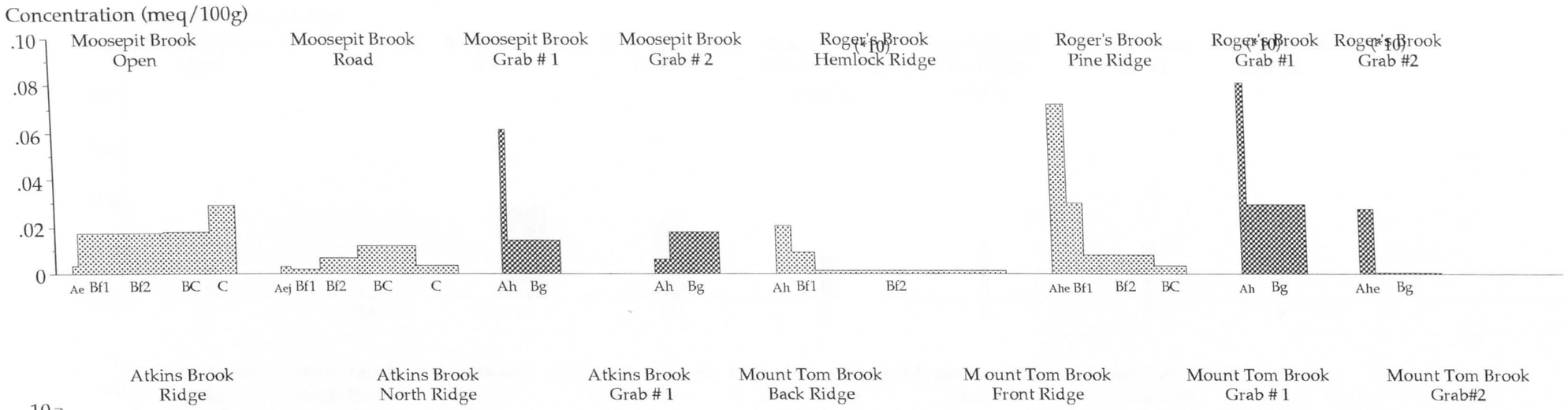


Fig. VI H. Exchangeable manganese concentrations (meq/100g) for mineral soil horizons (▨ upland soils; ▩ lowland soils).

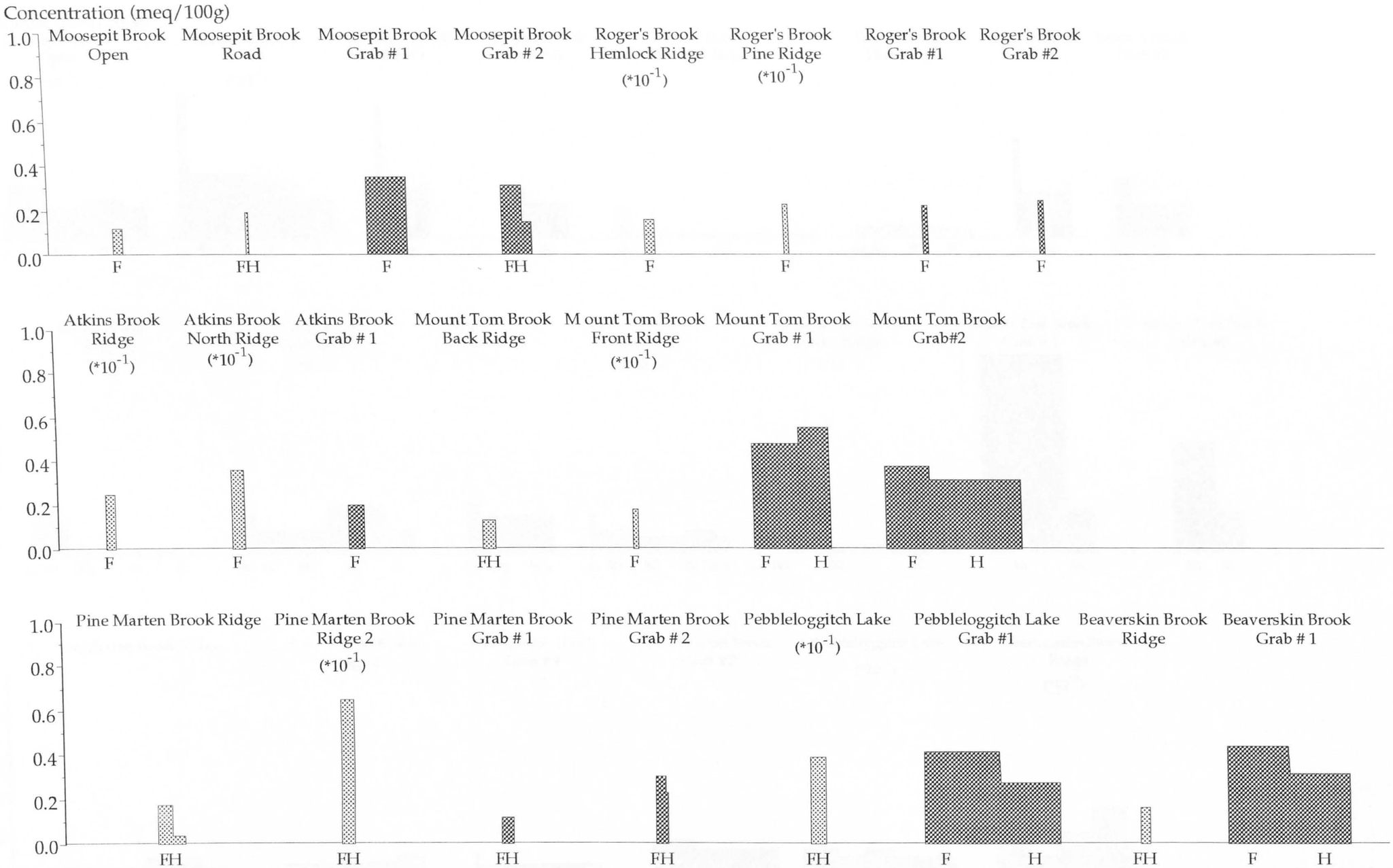
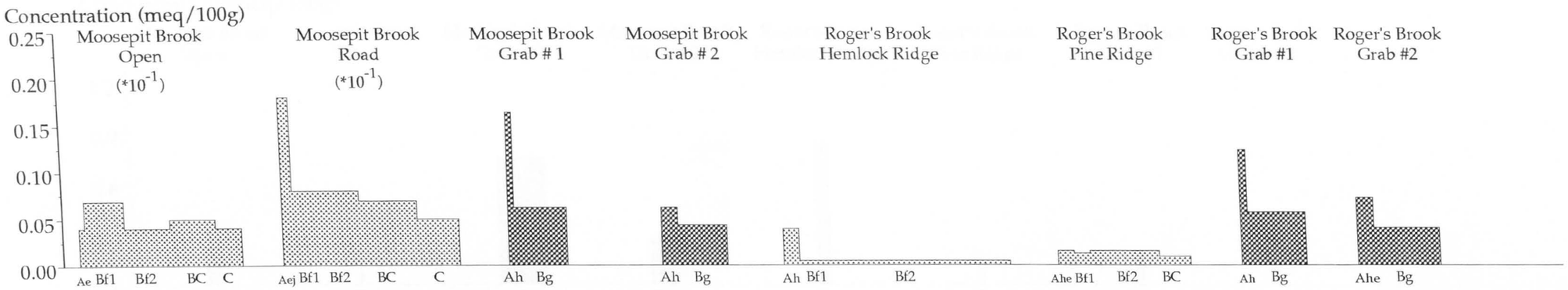
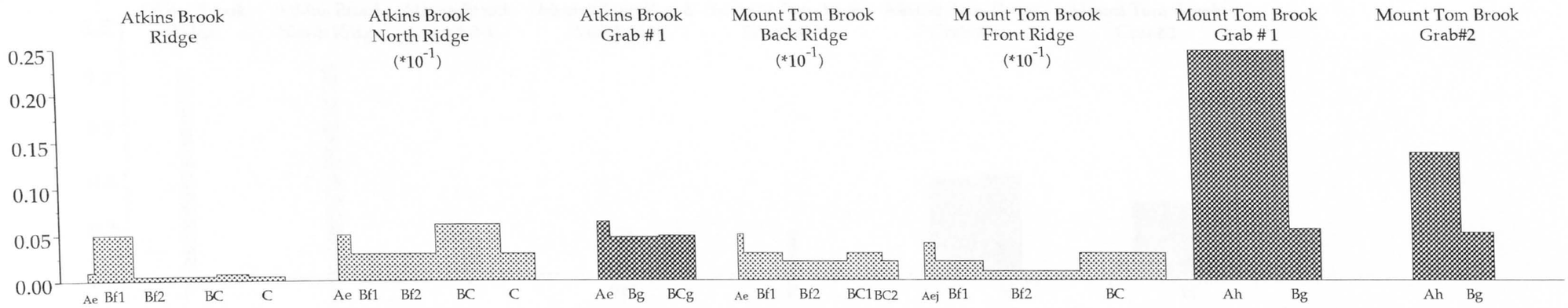


Fig. VI I. Exchangeable sodium concentrations (meq/100g) for organic horizons (▨ upland soils; ▩ lowland soils).





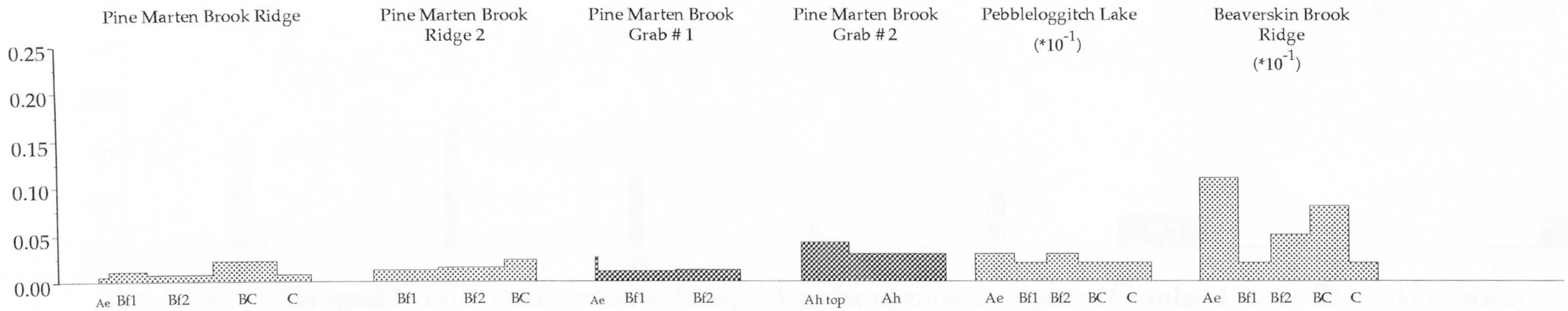


Fig. VI J. Exchangeable sodium concentrations (meq/100g) for mineral soil horizons (▨ upland soils; ▩ lowland soils).

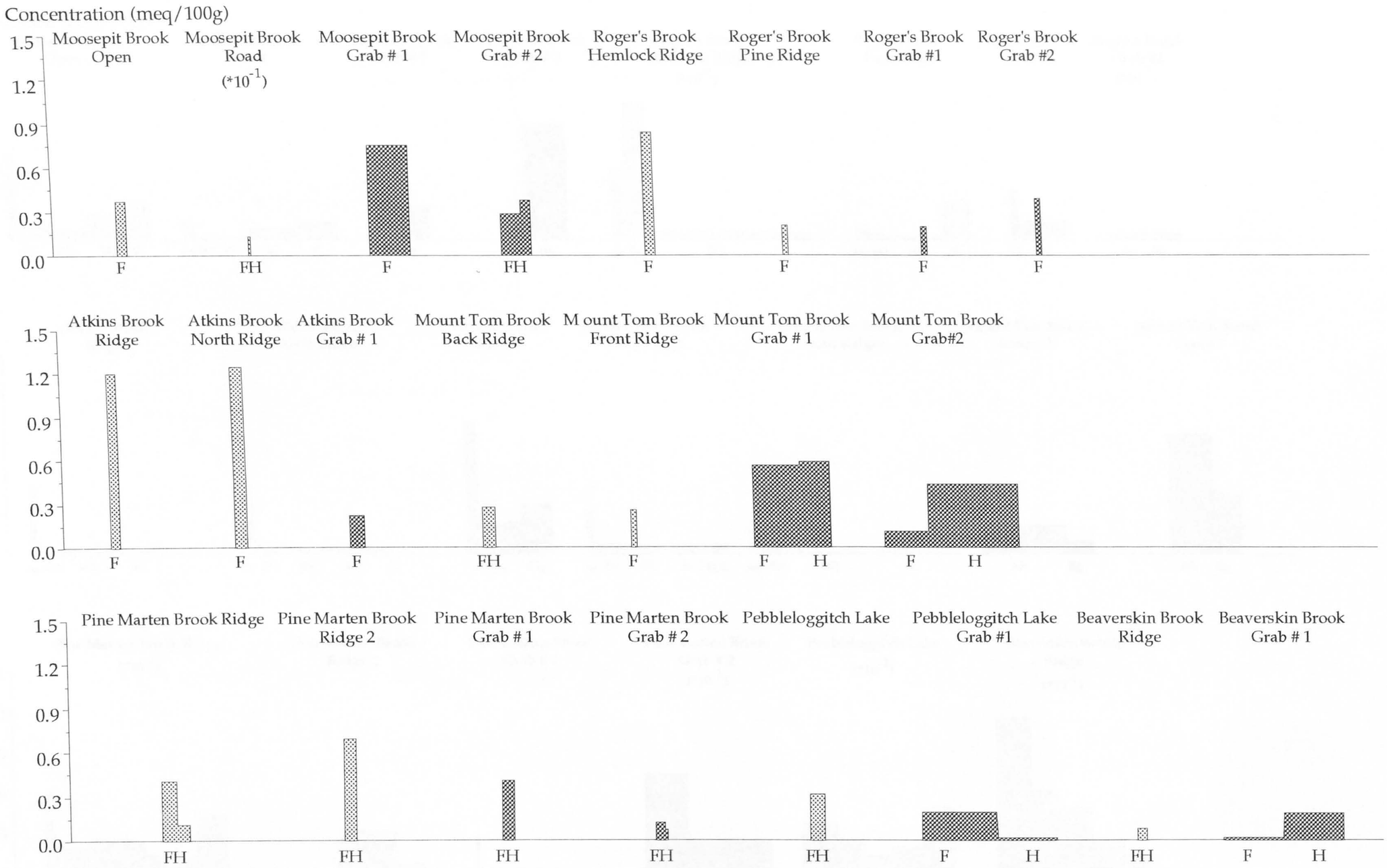


Fig. VI K. Exchangeable iron concentrations (meq/100g) for organic horizons (▨ upland soils; ▩ lowland soils).

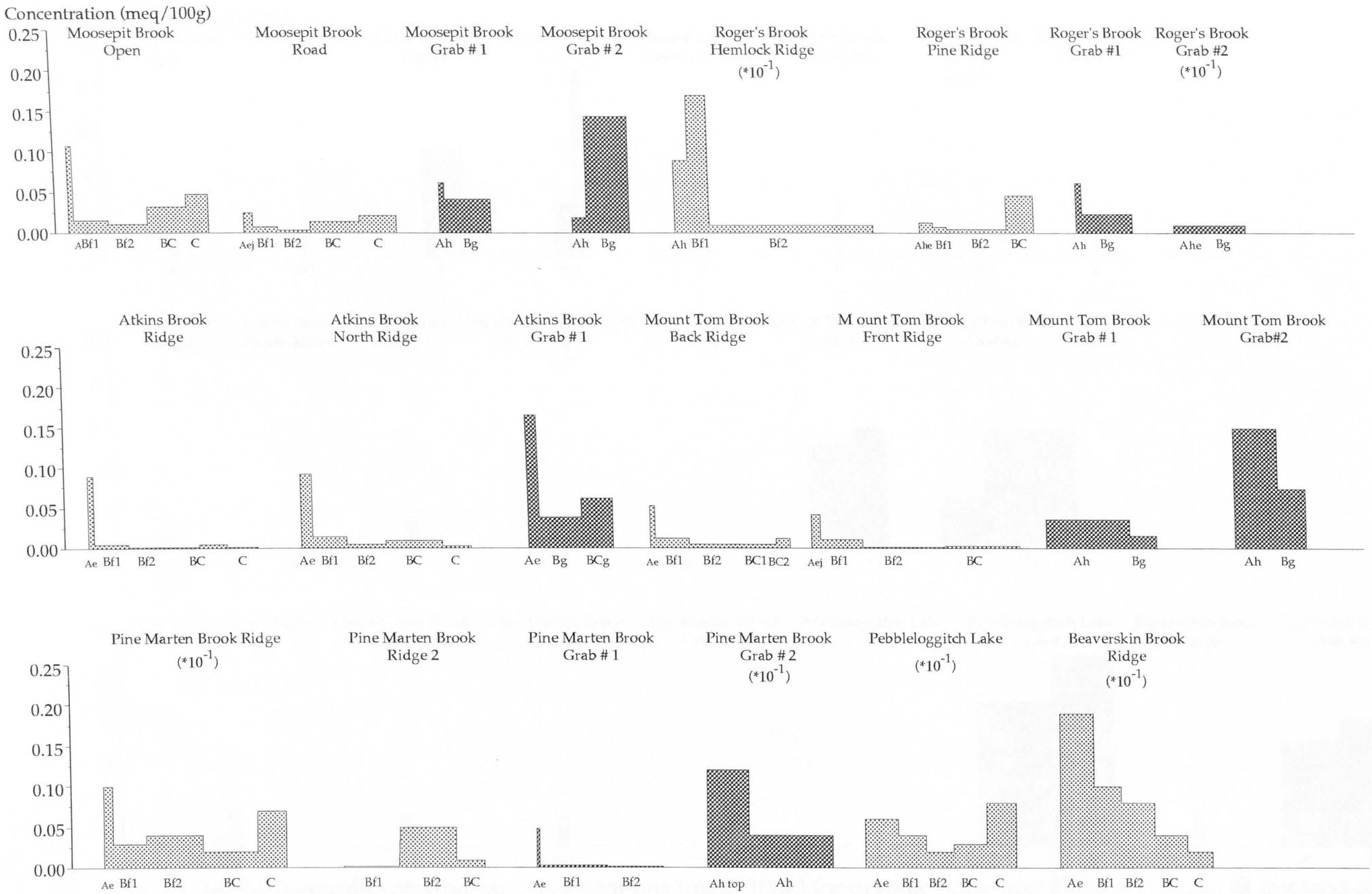


Fig. VI L. Exchangeable iron concentrations (meq/100g) for mineral soil horizons (▨ upland soils; ▩ lowland soils).

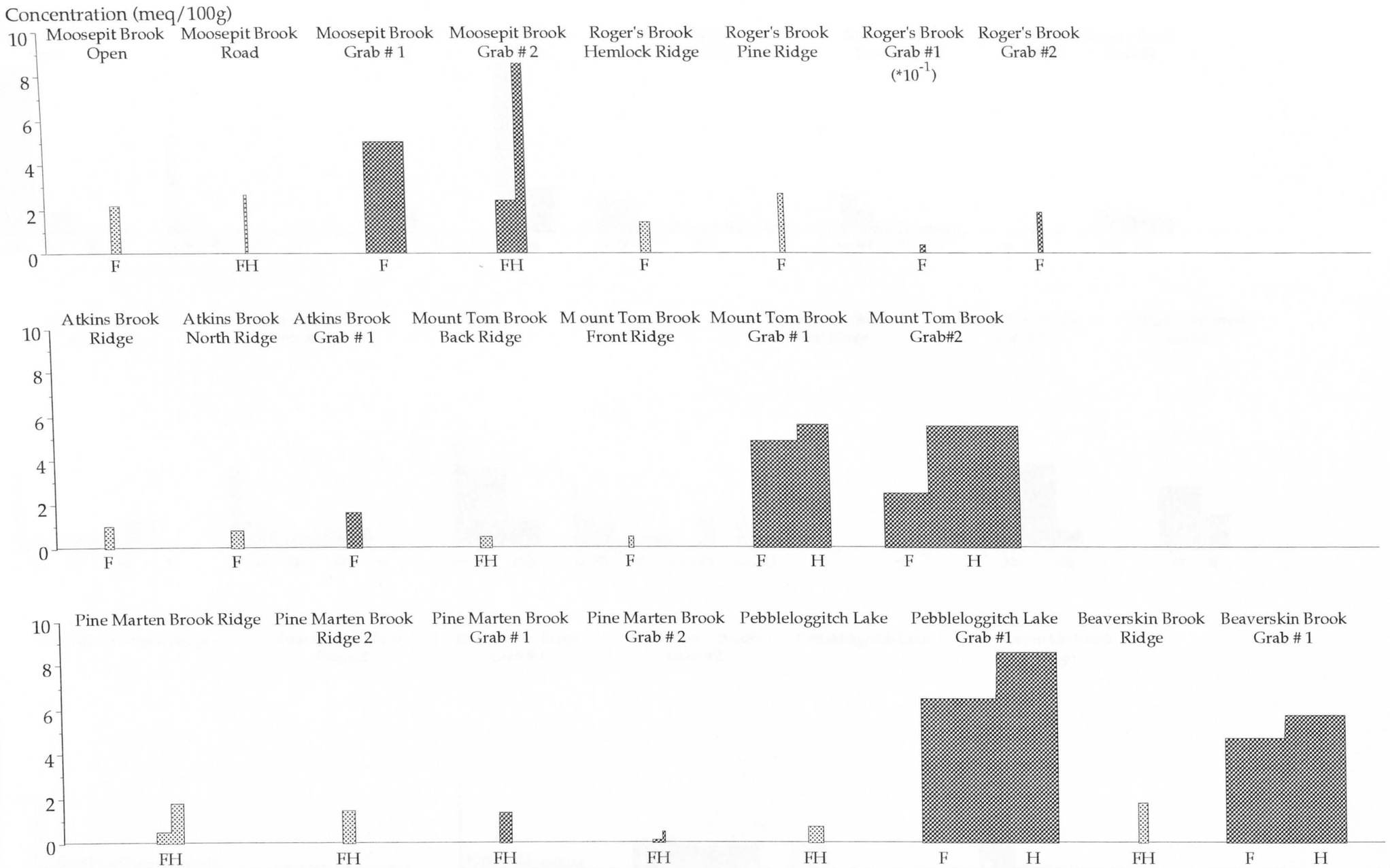


Fig. VI M. Exchangeable aluminum concentrations (meq/100g) for organic horizons (▨ upland soils; ▩ lowland soils).

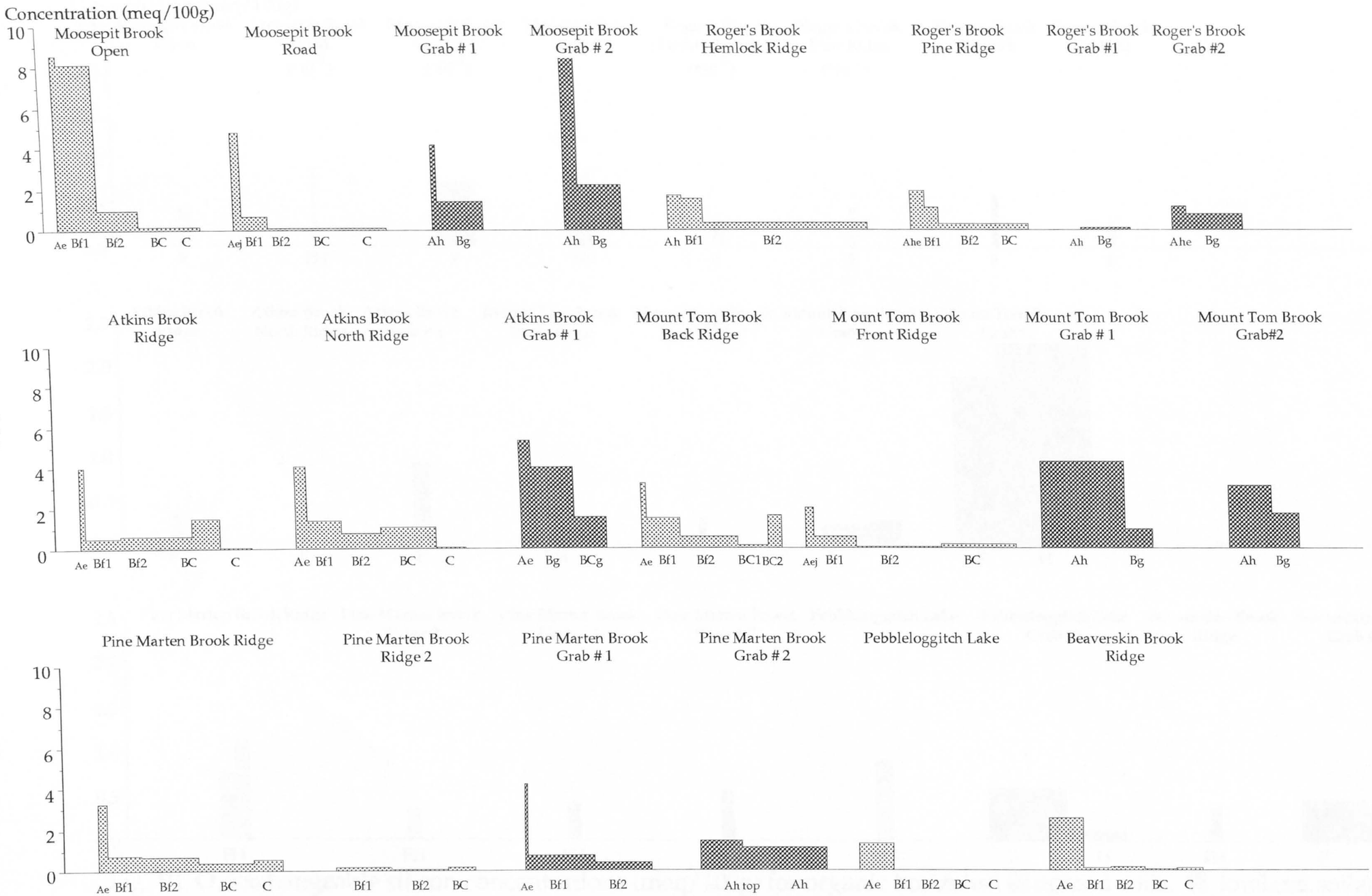


Fig. VI N. Exchangeable aluminum concentrations (meq/100g) for mineral soil horizons (▨ upland soils; ▩ lowland soils).

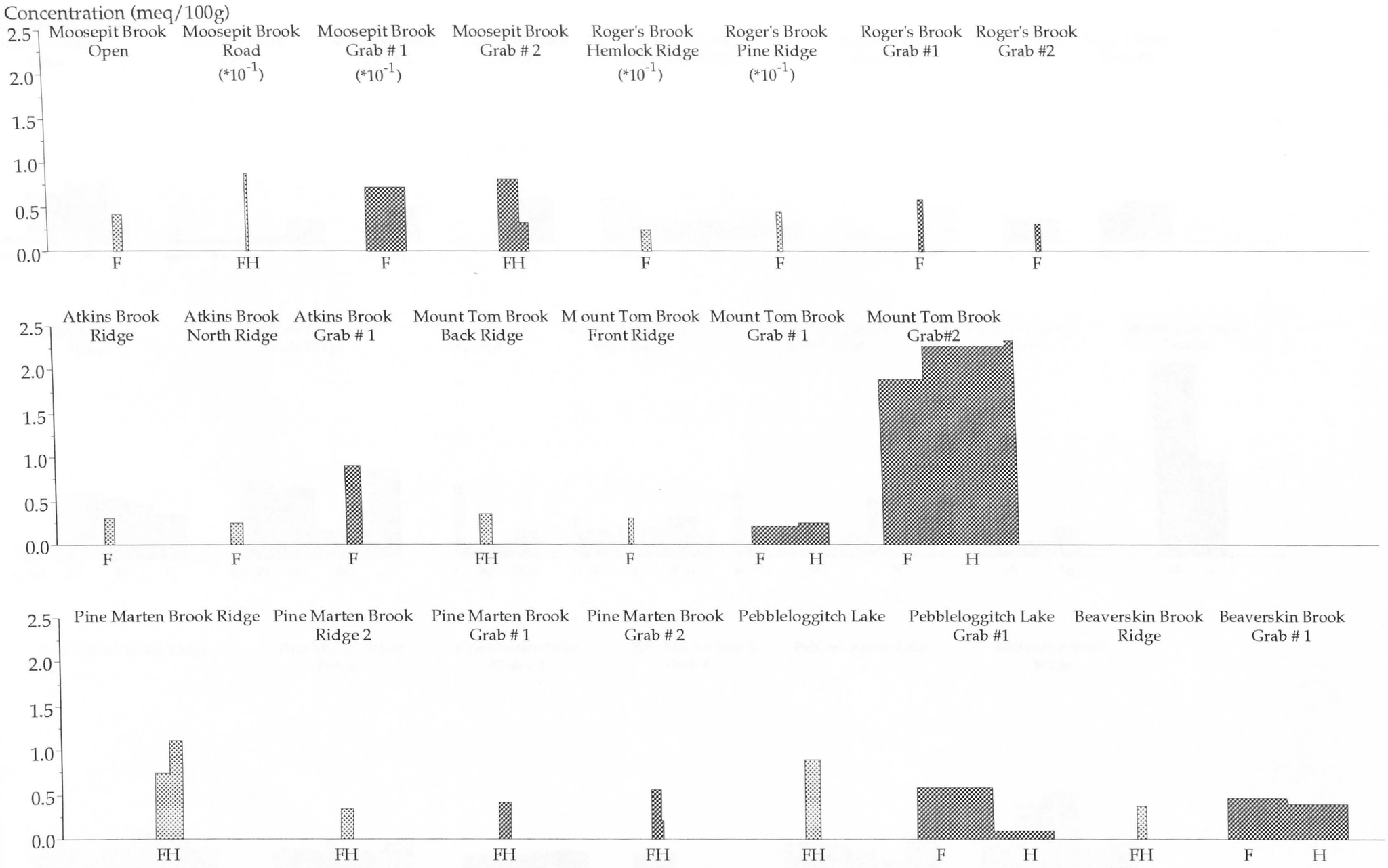
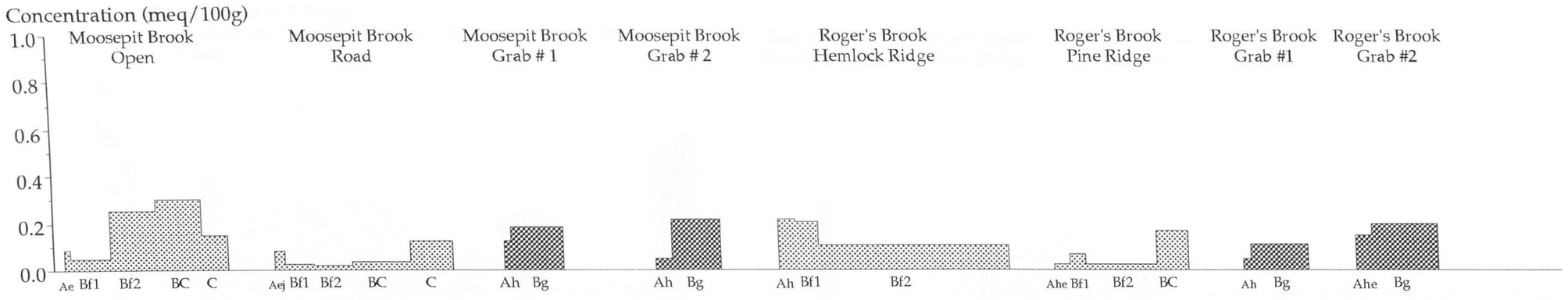
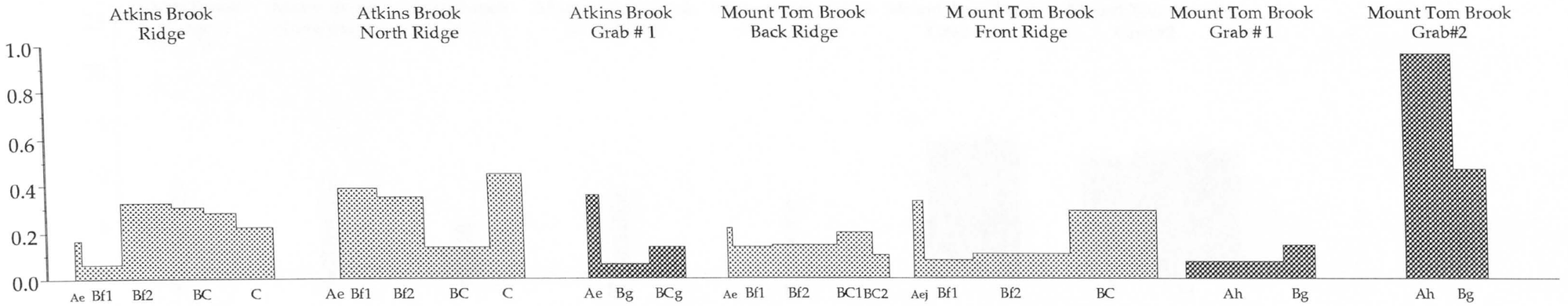


Fig. VI O. Exchangeable silicon concentrations (meq/100g) for organic horizons (upland soils; lowland soils).





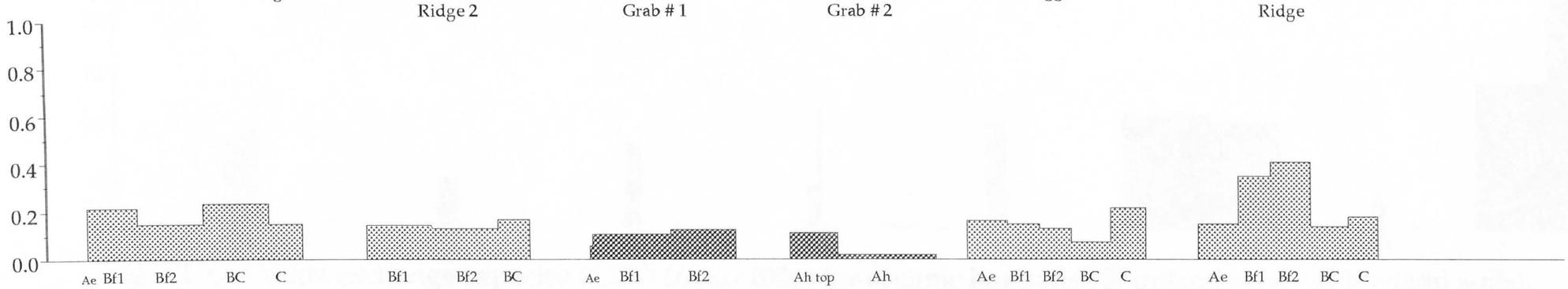


Fig. VI P. Exchangeable silicon concentrations (meq/100g) for mineral soil horizons (upland soils; lowland soils).

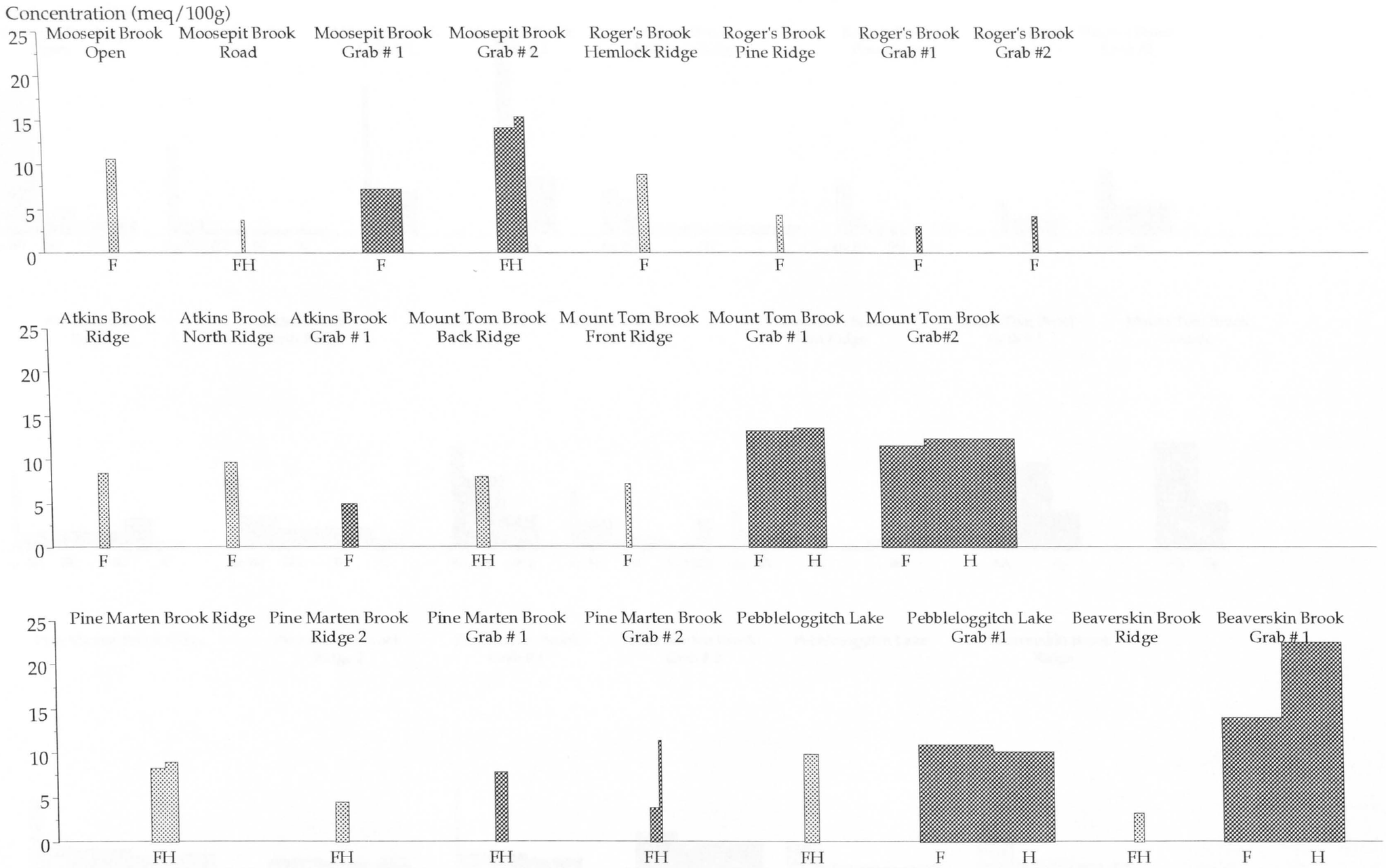


Fig. VI Q. Cation exchange capacity (CEC) (meq/100g) for organic horizons (upland soils; lowland soils).

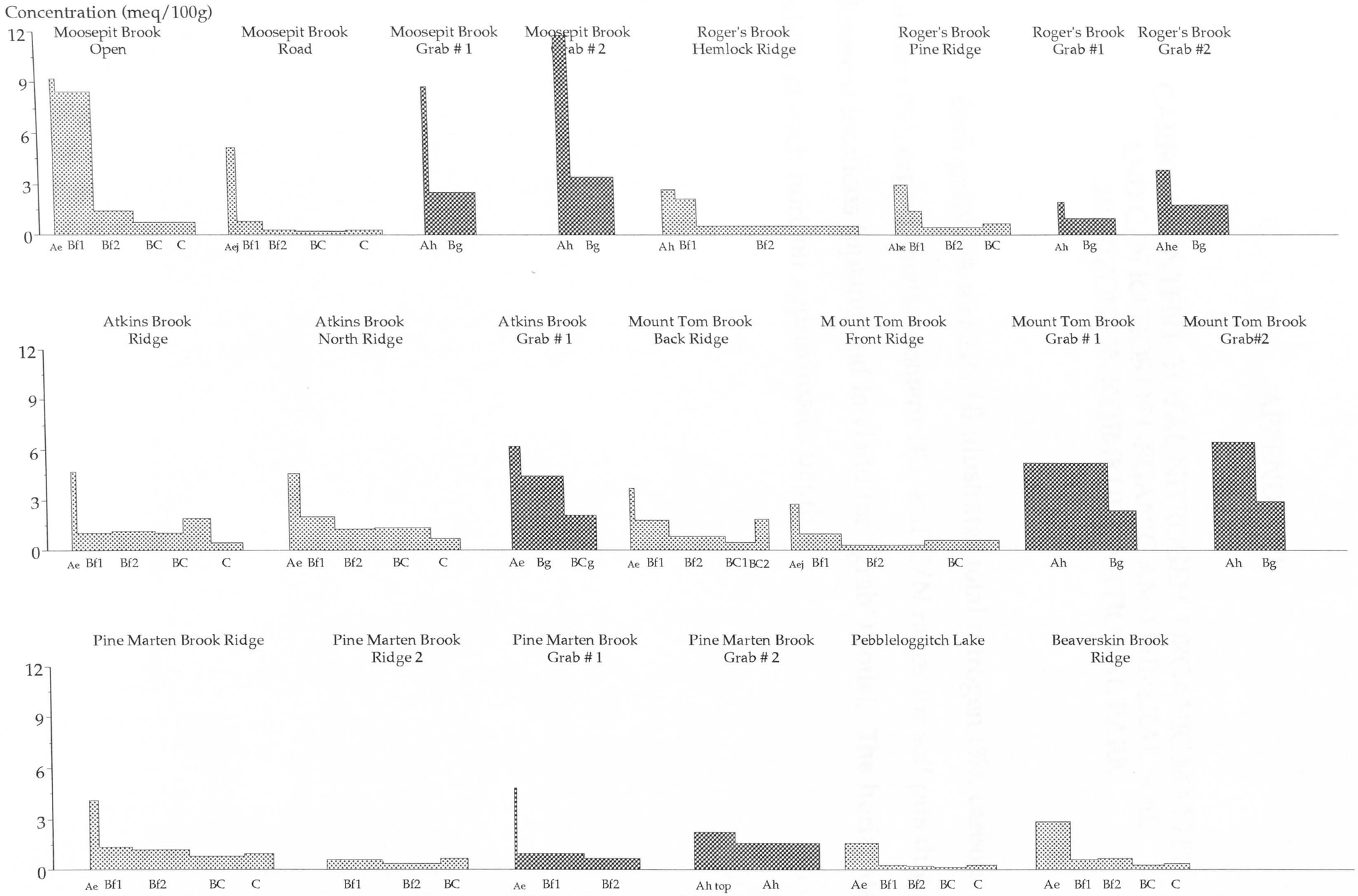


Fig. VI R. Cation exchange capacity (CEC) (meq/100g) for mineral soil horizons (▨ upland soils; ▩ lowland soils).

APPENDIX VII

CARBON CONTENT, TOTAL NITROGEN, ORGANIC MATTER, AND C/N RATIOS OF ORGANIC AND MINERAL SOIL HORIZONS IN KEJIMKUJIK NATIONAL PARK

Each graph (A through H) illustrates total nitrogen (%), carbon content (%), organic matter content (%), and C/N ratios for soil pits dug at 21 different locations [upland and lowland (or "grab") soils]. The horizontal width of each horizon approximates depth.

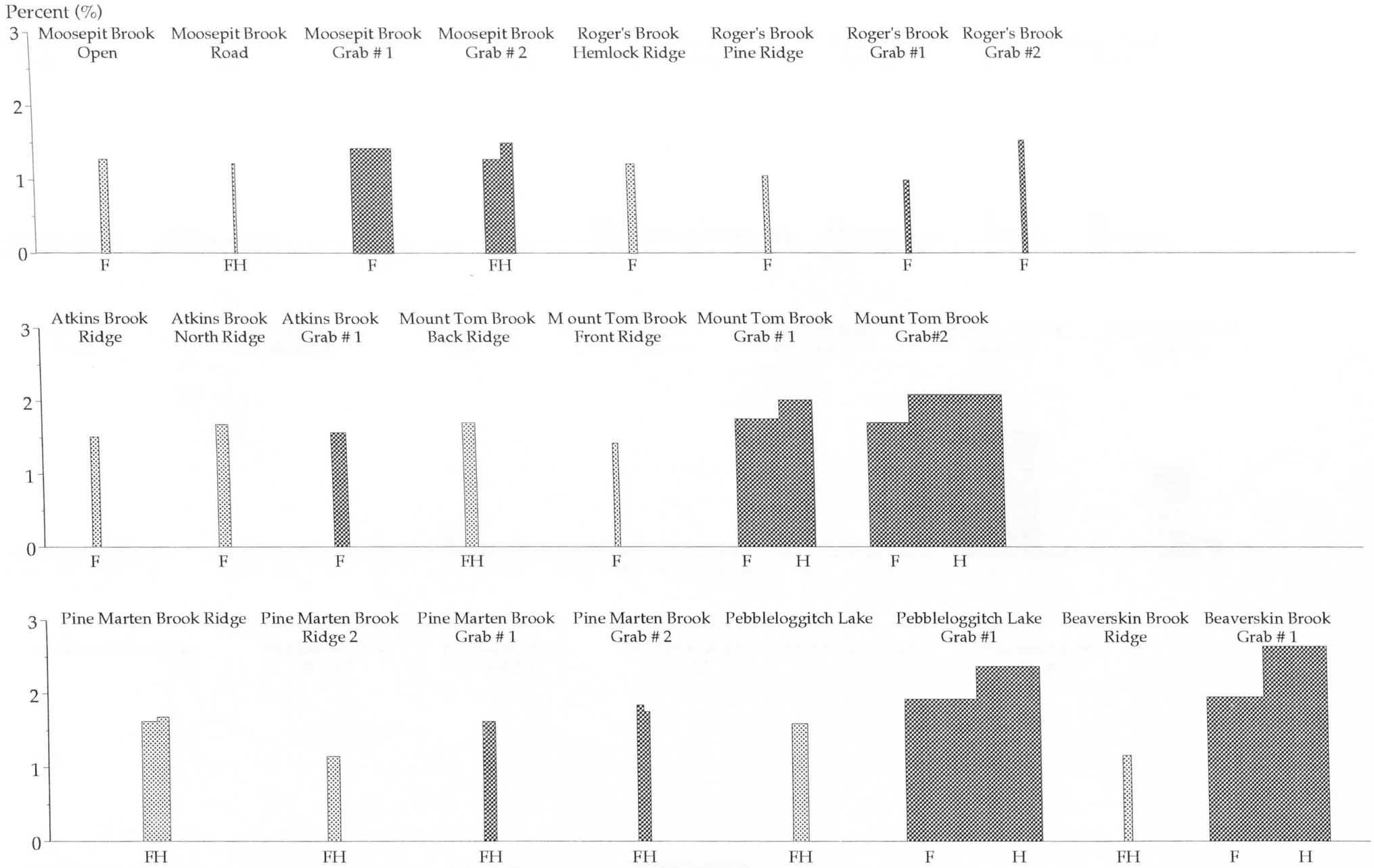


Fig. VII A. Total nitrogen (%) in organic horizons (▨ upland soils; ▩ lowland soils).

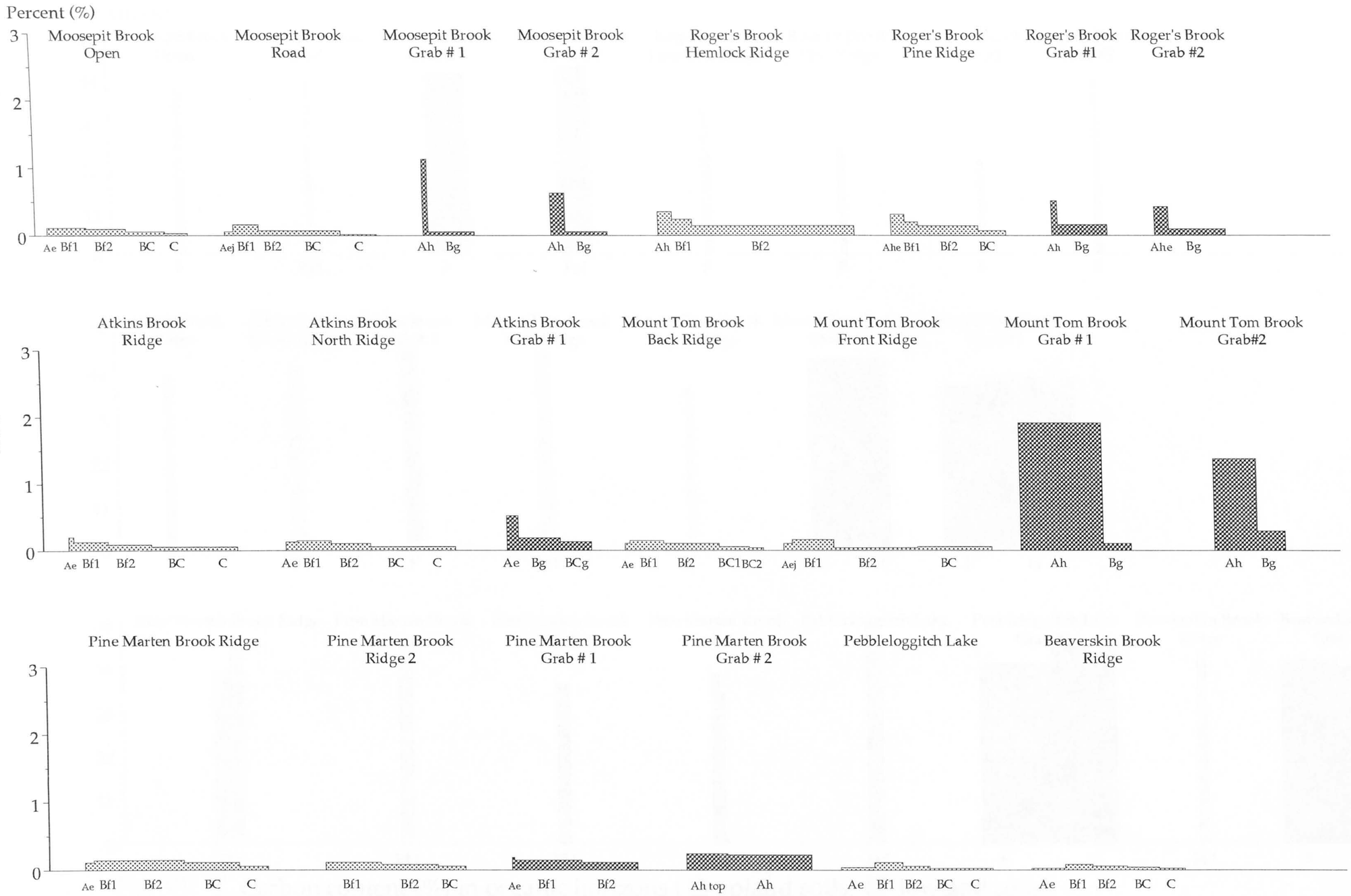


Fig. VII B. Total nitrogen (%) in mineral soil horizons (▨ upland soils; ▩ lowland soils).

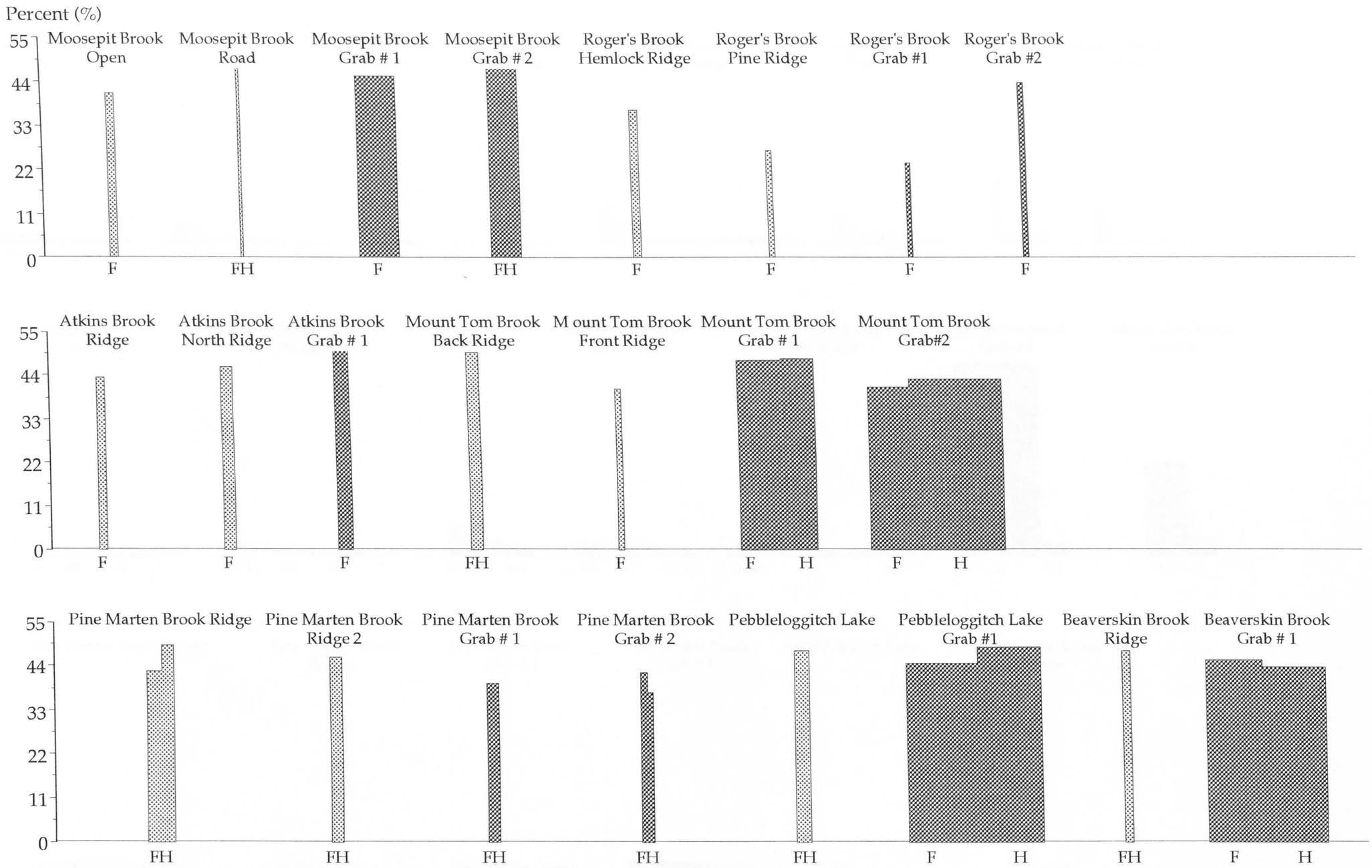


Fig. VII C. Carbon content (%) in organic horizons (upland soils; lowland soils).

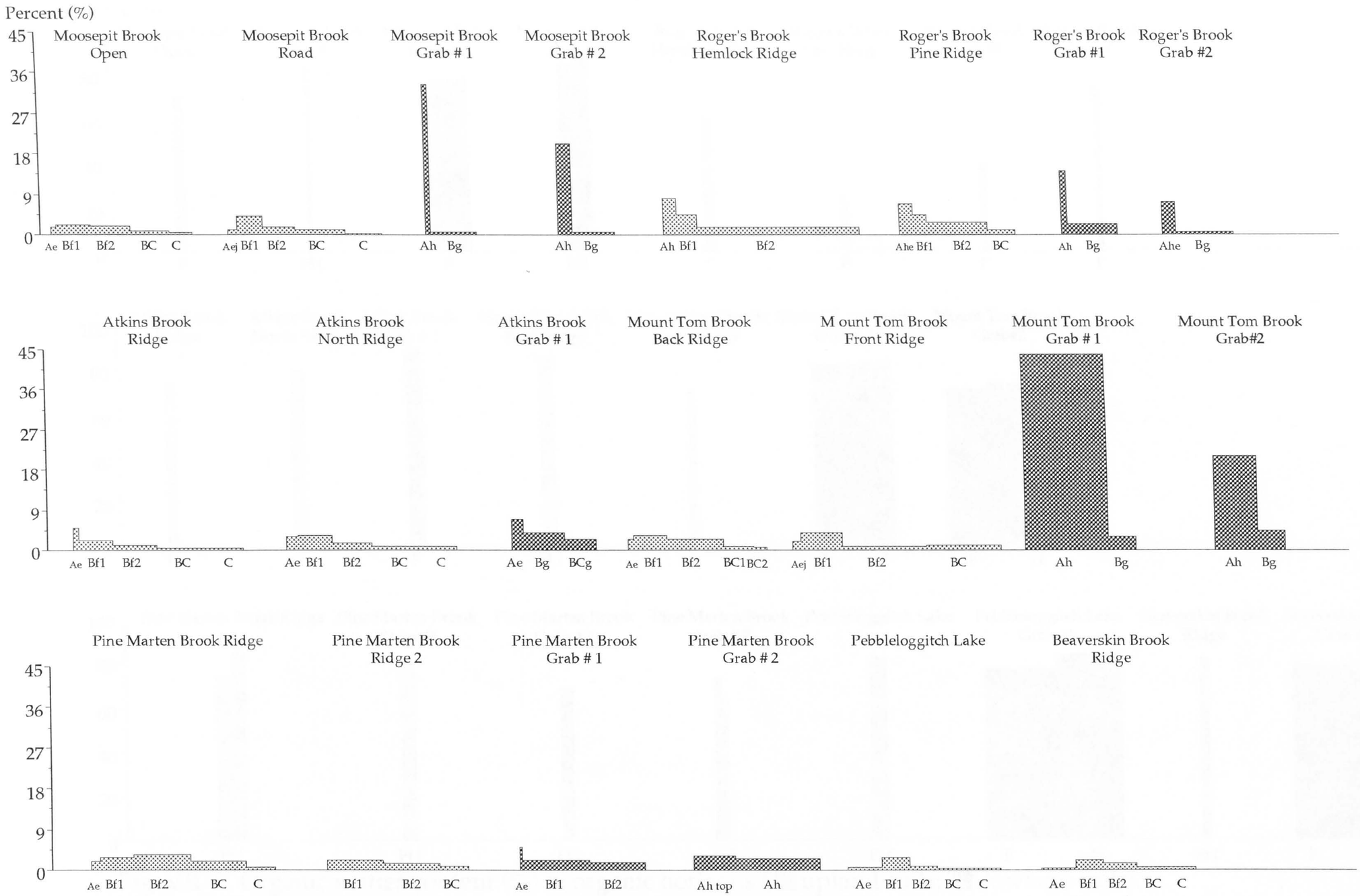


Fig. VII D. Carbon content (%) in mineral soil horizons (▨ upland soils; ▩ lowland soils).

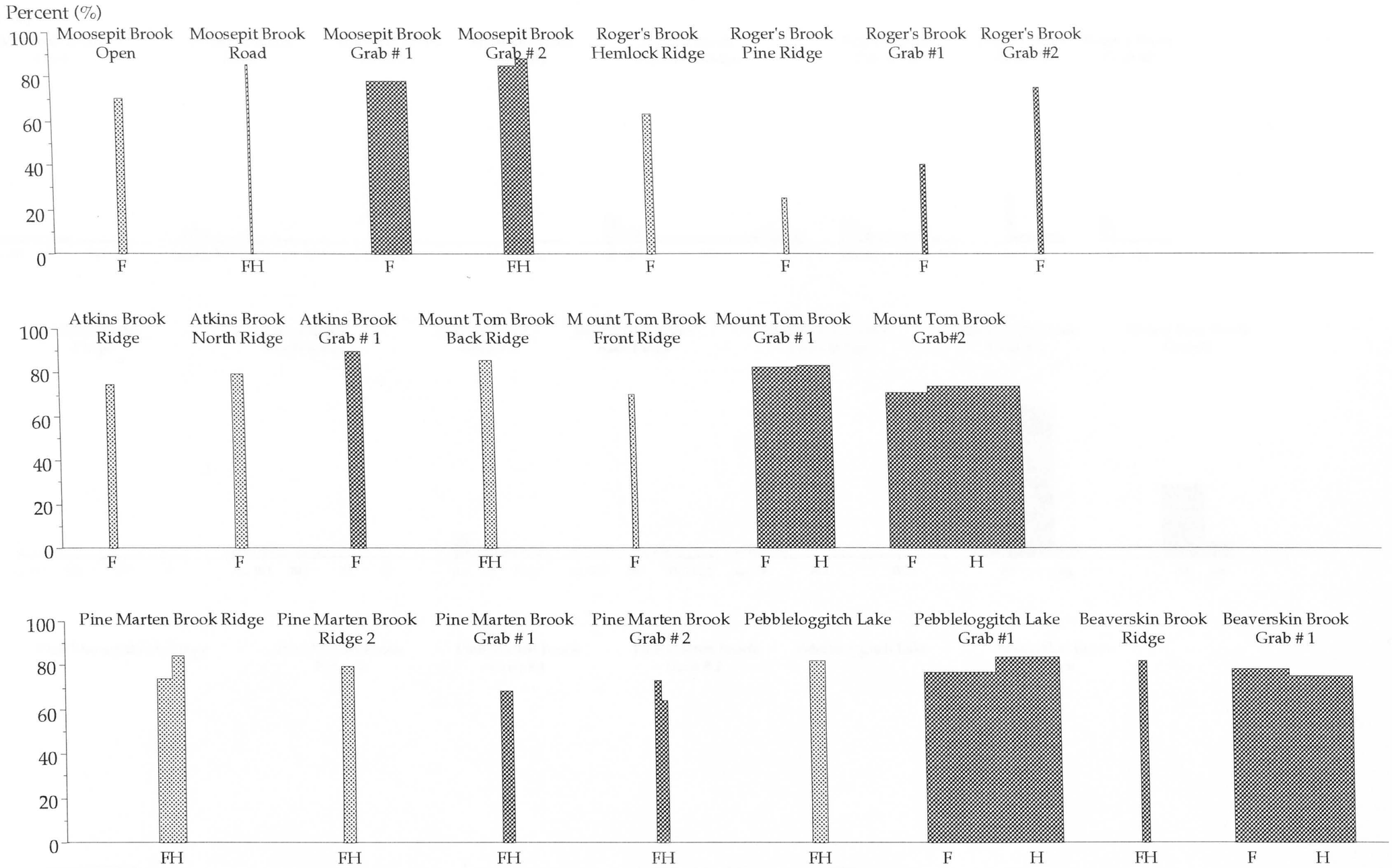


Fig. VII E. Organic matter content (%) in organic horizons (upland soils; lowland soils).

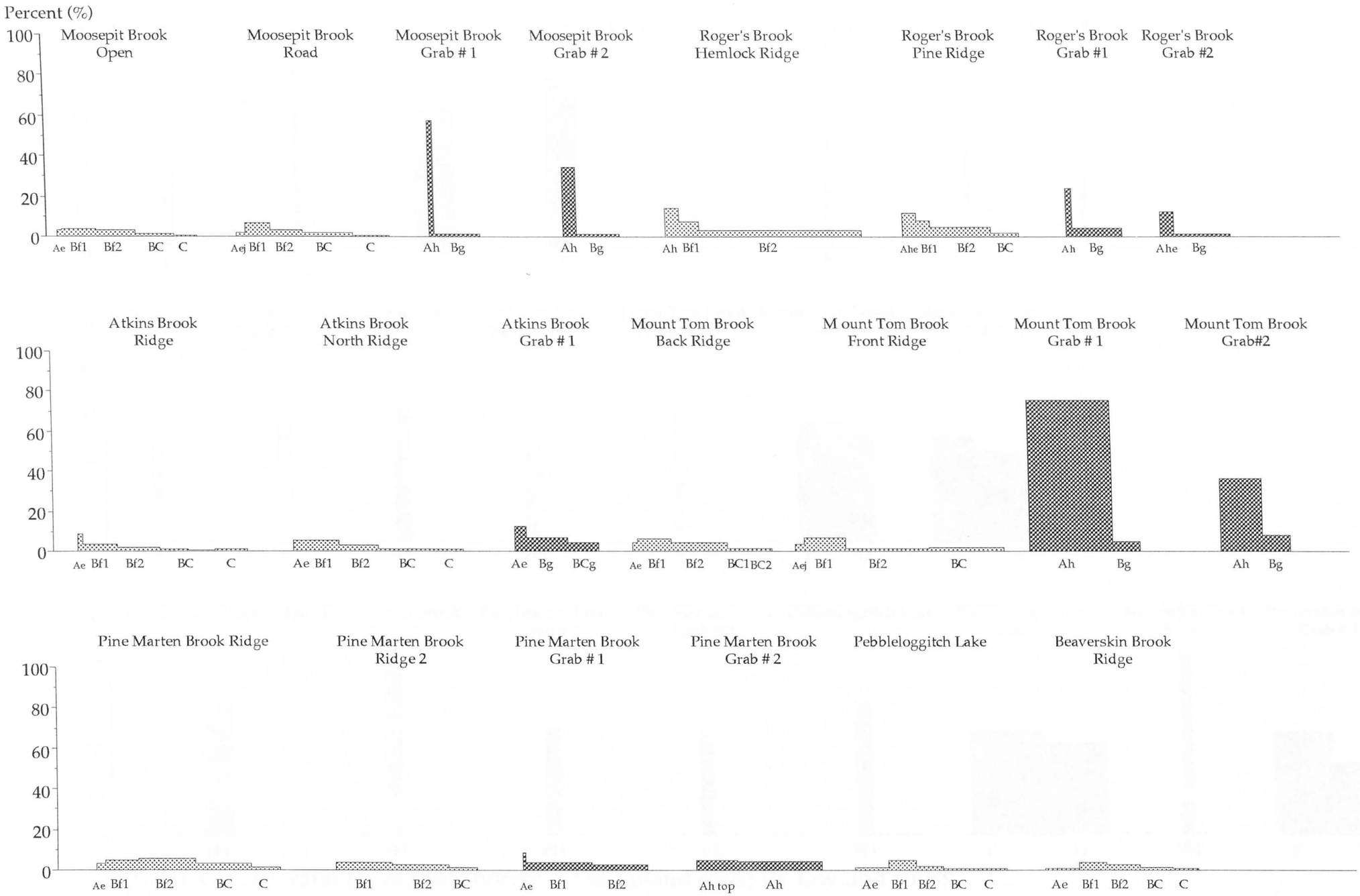
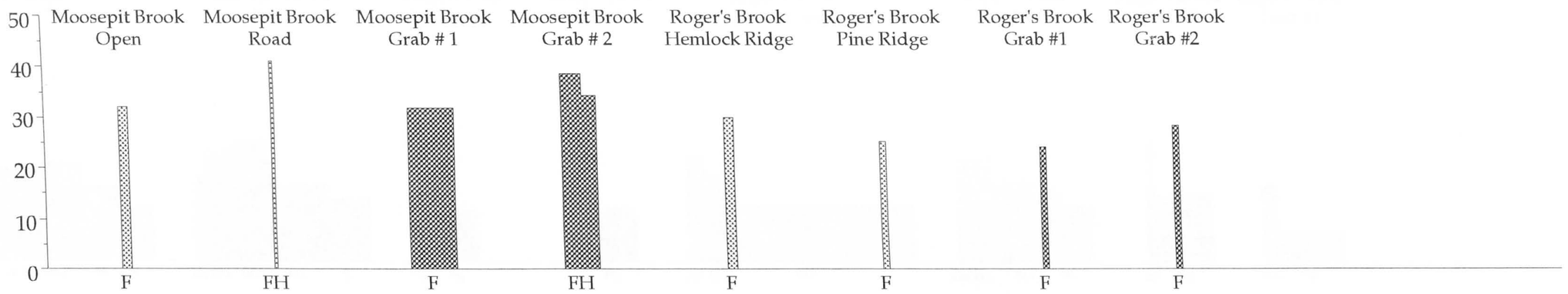
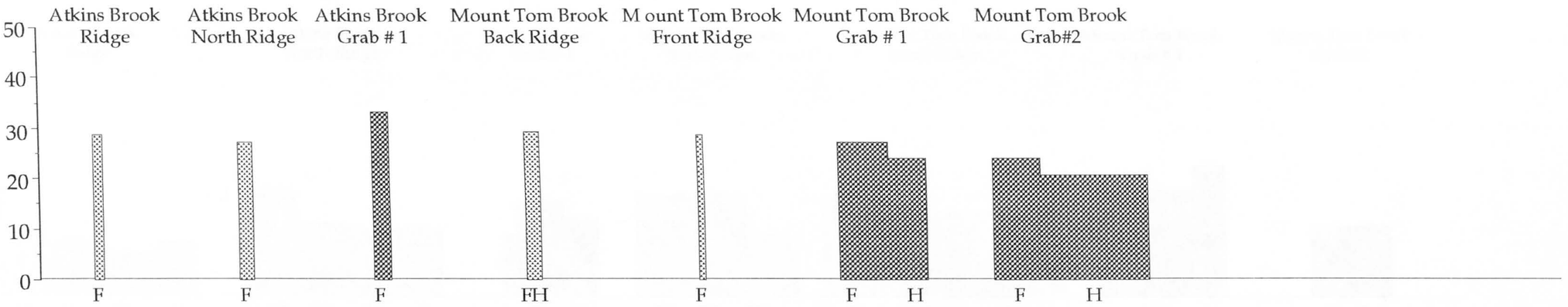


Fig. VII F. Organic matter content (%) in mineral soil horizons (▨ upland soils; ▩ lowland soils)





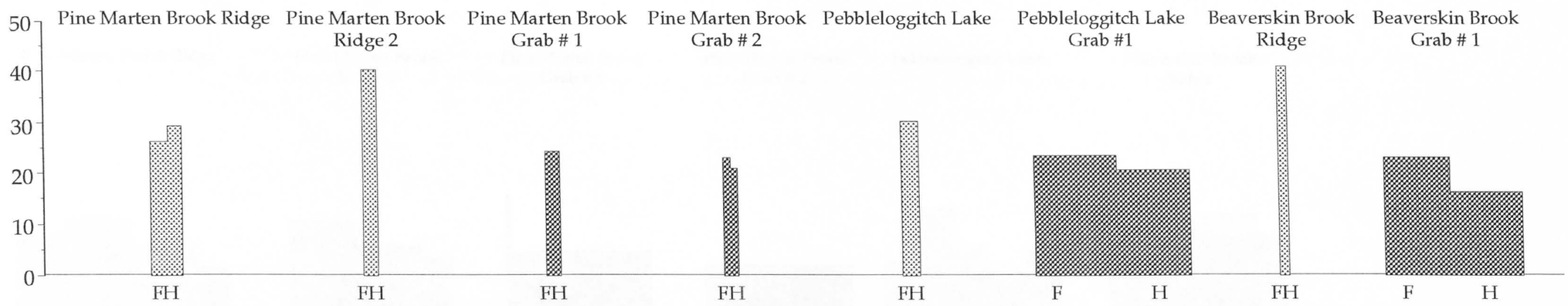
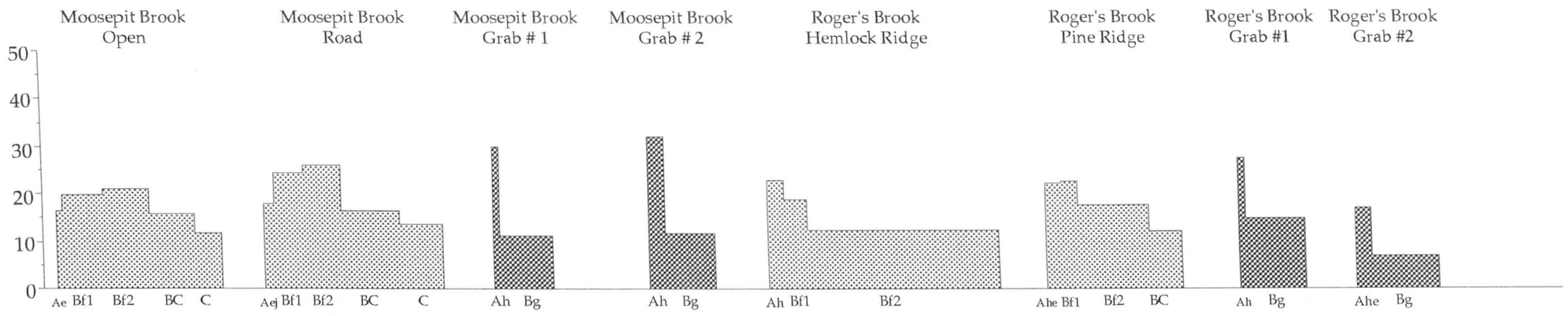


Fig. VII G. C/N ratio for organic horizons (upland soils; lowland soils).



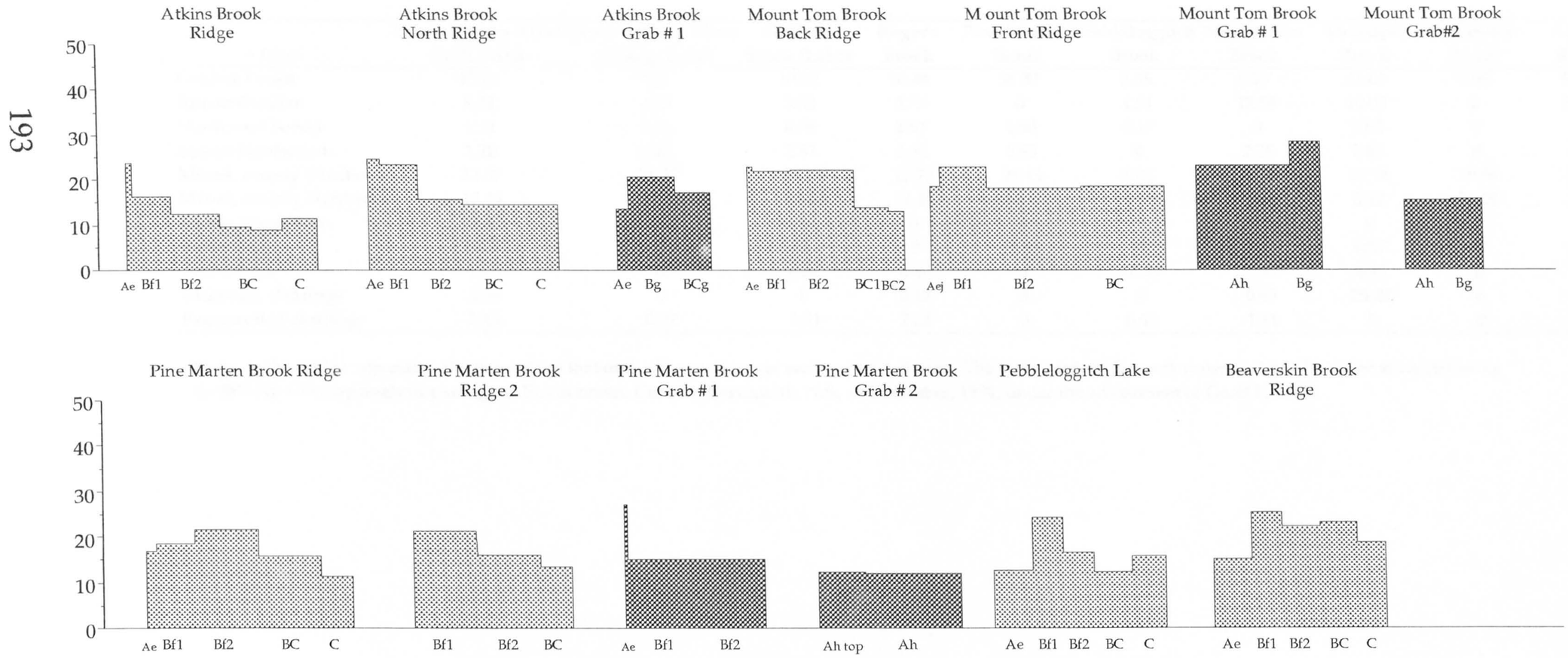


Fig. VII H. C/N ratio for mineral soil horizons (▨ upland soils; ▩ lowland soils)

APPENDIX VIII

SPANS GIS MAP ANALYSES

Class	Upper Mersey River (Mill Falls)	Lower Mersey River (George Lake)	Grafton Brook (Lake)	Roger's Brook	Pine Marten Brook	Pebbleloggitch Brook	Mount Tom Brook	Moosepit Brook	Beaverskin Brook	Atkin's Brook
Conifer Forest	43.70	7.81	10.02	58.44	38.37	3.85	3.77	42.63	8.85	52.92
Sparse Conifer	5.02	2.73	3.53	2.75	0	4.91	12.58	10.00	0	26.18
Hardwood Forest	1.11	1.22	0.96	2.51	1.80	3.17	0	3.62	0	0
Sparse Hardwood	1.20	0.63	2.81	1.92	6.65	0	2.28	2.65	0	0.19
Mixed, mainly Conifer	22.87	26.42	21.15	12.22	24.45	8.06	49.52	12.18	39.06	10.46
Mixed, mainly Hardwood	18.14	60.92	53.89	19.16	21.17	57.04	28.61	3.12	52.09	2.41
Poorly Vegetated	0.38	0	0	0	0	0	0	0	0	0
Open Bogs	0.05	0	0	0	7.55	0	0	0.07	0	0.26
Treed Bogs	1.75	0	4.82	0.60	0	16.49	1.35	0.45	0	4.26
Clearcuts, clearings	3.36	0	0	0.12	0	0	0.49	25.27	0	0.94
Regenerated clearings	2.42	0.27	2.81	2.28	0	6.48	1.41	0	0	2.37

Note: each number represents the percentage that each class covers over each watershed area. The classifications for each watershed in KNP were analyzed using the SPANS GIS map analysis package at Environment Canada, Dartmouth, N.S., in December, 1994, under the advisement of Geoff Howell.

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