# Soil and plant chemistry of an Atlantic white cedar wetland on the Inner Coastal Plain of Maryland

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Atlantic white cedar (*Chamaecyparis thyoides* (L.) BSP.) wetlands are widely distributed along the Atlantic coast, yet there is very little information on their nutrient dynamics. In this paper we present data on the chemical composition of soils and plant tissues for one of the last remaining stands of *Chamaecyparis* on the Inner Coastal Plain of Maryland. Comparisons are made among the *Chamaecyparis* site, five similar nearby wetlands without *Chamaecyparis*, and other *Chamaecyparis* sites. The Atlantic white cedar site in Maryland had a distinct soil chemistry characterized by significantly higher Ca, Mg, and Na concentrations and high pH. There were significant differences between wetlands, within wetlands (forested versus bog habitats), and between types of plants (herbaceous versus woody) for most plant nutrients. Woody and herbaceous species at the Atlantic white cedar site almost always had higher concentrations of the 15 elements measured than they did at the other sites. However, nutrient concentrations of *Chamaecyparis* shoots, when compared with reported plant requirements, indicate a possible deficiency of N and P, low K, and a pronounced accumulation of Pb.

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Les marécages à cèdres blancs de l'Atlantique (*Chamaecyparis thyoides* (L.) BSP.) sont communs le long de la côte de l'Atlantique; pourtant, il n'existe que peu d'information sur leur dynamique trophique. Dans cet article, nous présentons des données sur la composition des sols et des tissus végétaux pour un des derniers bouquets subsistants du *Chamaecyparis* sur la plaine côtière interne du Maryland. Des comparaisons sont faites entre le site à *Chamaecyparis*, cinq marécages voisins semblables sans *Chamaecyparis* et d'autres sites à *Chamaecyparis*. Le site à cèdres blancs de l'Atlantique, au Maryland, avait une chimie de sol caractérisée par des concentrations significativement plus élevées de Ca, Mg et Na et un pH élevé. Il y avait des différences significatives entre les marécages, à l'intérieur des marécages (habitats forestiers versus marécageux) et entre les types de plants (herbacés versus ligneux) pour presque tous les éléments nutritifs. Les espèces, tant ligneuses qu'herbacées, au site à cèdres blancs de l'Atlantique, avaient presque toujours des concentrations plus élevées pour 15 éléments mesurés, que celles des autres sites. Cependant, les concentrations d'éléments nutritifs dans les pousses du *Chamaecyparis*, comparées aux exigences des plantes d'après la littérature, indiquent une déficience possible en N et P et une pénurie de K de même qu'une accumulation importante de Pb.

[Traduit par la revue]

## Introduction

Considerable information is available on the natural history of plant and animal species in Atlantic white cedar wetlands (Laderman 1987). In contrast, there have been few studies of ecological processes within wetlands dominated by this species (Day 1979, 1982, 1984; Day and Dabel 1978; Gomez and Day 1982; Bandle and Day 1985) and there are few data on nutrient pools and transfer rates in Atlantic white cedar ecosystems. In this paper, we summarize chemical data for soils and plant tissues from one of the last remaining stands of Atlantic white cedar on the western shore of Maryland (Hull and Whigham 1987). Our primary objective was to characterize the soil and plant chemistry of forested and nonforested (hereafter referred to as bog) habitats in the Atlantic white cedar wetland and compare data from that site with data from similar habitats at five nearby wetlands that are floristically similar but do not contain *Chamaecyparis*. A second objective was to compare *Chamaecyparis* tissue nutrient concentrations with other species at the Maryland site and other sites throughout its range.

## Site description

Vegetation of the six wetlands, located near Annapolis, MD, on the Inner Coastal Plain, have been described by Hull and Whigham (1987). Cypress Creek (0.44 ha), the only wetland with *Chamaecyparis*, and Round Bay (>25 ha) are the only sites that have not been hydrologically altered. Angel's Bog (2.2 ha), Eagle Hill (0.6 ha), North Grays Creek (1.9 ha), and South Grays Creek (2.7 ha) wetlands were completely forested before they were altered by the placement of earthen dams across the floodplains. Bog vegetation developed in the ponds formed behind the dams. At Round Bay, bog vegetation developed in a power-line corridor that was cut through the floodplain forest.

Cypress Creek is the only wetland located near (100 m) a major highway and it is also the only one that is physically close enough to an estuary to be flooded with brackish water during extremely high spring or storm tides.

Forested habitats are dominated by *Acer rubrum* L., *Amelanchier canadensis* (L.) Medicus, *Magnolia virginiana* L., and *Nyssa sylvatica* Marshall. The most abundant shrub species are *Clethra alnifolia* L., *Gaylussacia frondosa* (L.) T. G., *Ilex laevigata* (Pursh) Gray, *Leucothoe racemosa* (L.) Gray, *Rhododendron viscosum* (L.) Torrey, and *Vaccinium corymbosum* L. *Osmunda cinnamomea* L., *Symplocarpus foetidus* (L.) Nutt., and *Sphagnum* sp. dominate the herb layer in the forested areas. The bogs are in various stages of succession and are dominated by small individuals of *Acer rubrum* and by several shrub species (*Chamaedaphne calyculata* (L.) Moench, *Clethra alnifolia*, *Decodon verticillatus* (L.) Ell., *Rhododendron viscosum*, *Vaccinium corymbosum*, and *Vaccinium macrocarpon* Ait.). Dominant herbs are *Juncus abortivus* Chapman, *Nymphaea odorata* Aiton, *Rhynchospora alba* (L.) Vahl, *Triadenum virginicum* (L.) Raf., *Utricularia fibrosa* Walter, *Xyris ambigua* Beyrich, and *Sphagnum* sp. In addition to quantitative descriptions of the wetland vegetation in Hull and Whigham (1987), Sipple and Klockner (1980, 1984) and Sipple (1977*a*, 1977*b*) have provided extensive species lists for the six wetlands. Scientific names are based on United States Department of Agriculture, Soil Conservation Service (1982).

## Methods

Ten 50-cm soil cores were collected from the forested and 10 from bog habitats in August 1979. Sampling locations within each habitat were randomly determined. All cores were frozen the day of collection and stored until they were transported, still frozen, to Duke University for analysis. Cores were analyzed for moisture content (MOIST), pH, organic matter (OM), total nitrogen (N), and total phosphorus (P), extractable ammonium nitrogen ($NH_4$-N), nitrate nitrogen ($NO_3$-N), aluminum (Al), and iron (Fe) and extractable calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na).

All laboratory analyses except N and P were conducted on undried soil to minimize alterations of the natural chemistry of the soils (Allen 1974; Richardson et al. 1978). Initial moisture values were used to convert fresh weight to dry weight equivalents. Soils were dried at 105°C for 24 h and percent moisture was calculated as (fresh weight − dry weight)/fresh weight. Soil pH was measured potentiometrically using a 1:10 soil to water weight ratio. Organic matter was determined by ashing 1 g of dried soil at 500°C for 8 h and expressing the weight loss as (dry weight − ash weight)/dry weight. Exchangeable cations were determined by atomic adsorption spectrophotometry (Perkin-Elmer 1978) following extraction with 1 M ammonium acetate at pH 4.8 (Andersson 1975). Ammonium-N and $NO_3$-N were extracted with 2 N KCl (Bremmer 1965) and analyzed with the cadmium reduction reaction technique and the Berthelop reaction (Environmental Protection Agency 1974). Extractable noncrystalline Al and Fe were determined on 5.0 g dry weight equivalent of soil using 100 mL of acid oxalate solution (Saunders 1965; Richardson 1985). Total N and P were determined on dried soils that were sieved (2-mm mesh) and digested with sulfuric acid and hydrogen peroxide (Lowendorf and Dominski 1974). The digests were analyzed for N by ammonia–salicylate complexation and P by phosphomolybdate complexation (Technicon 1975).

Plants were sampled in August during the same week that soils were collected. Terminal shoots, current years growth only, of woody species and leaf material of herbaceous species were collected from three individuals in each habitat at each site. Shoots of woody species were collected since leaves and shoots of *Chamaecyparis* are very difficult to separate. The material that was collected will hereafter be called leaves since more than 75% of the biomass consisted of leaves. Samples were collected from plants that overlapped randomly positioned transects made through each habitat.

*Vaccinium macrocarpon* Ait., *Chamaedaphne calyculata*, and *Decodon verticillatus* were sampled in bog habitats at each site. *Clethra alnifolia, Magnolia virginiana, Acer rubrum*, and *Vaccinium corymbosum* were sampled in forested and bog habitats at all sites. *Chamaecyparis* was sampled in both forested and bog habitats at Cypress Creek. *Symplocarpus foetidus, Osmunda cinnamomea*, and *Arundinaria gigantea* (Walter) Walter ex Muhl. were the three herbs sampled in the forested habitats. *Triadenum virginicum* and *Rhynchospora alba* were selected as representatives of herbaceous species in bog habitats.

Leaf samples were dried at 60°C, ground in a Wiley mill to pass through a 2-mm screen, and sent to Pennsylvania State University, where they were analyzed for P, K, Ca, Mg, sulfur (S), manganese (Mn), Fe, copper (Cu), boron (B), Al, zinc (Zn), strontium (Sr), lead (Pb), and silica (Si). Analyses were performed on an individually coupled plasma emission spectrometer, Applied Research Laboratory model 137, using procedures described in Dahlquist and Knoll (1978). Nitrogen analyses were performed in duplicate by digestion to ammonia salts, using sulfuric acid and hydrogen peroxide with Hangar boiling chips as catalysts (Martin 1972). The ammonia was then distilled and measured by Nesslerization (American Public Health Association 1976).

Soil data were either log or arc sine and square root transformed prior to analysis for site, habitat, and site × habitat effects, using analysis of variance (Ray 1982). The same procedures were used on plant data except that plant type (herbaceous or woody) was added as a variable. Means for soil and plant data were compared using Tukey's Studentized range tests. Data were also compared using stepwise discriminant analysis (Ray 1982). Significance levels referred to in the text are at least at the 0.05 probability level.

## Results

### Soil

#### Between-wetland comparisons

Mean values for soil variables at each site and habitat are shown in Table 1. Two-way interactions were significant in only 3 of a possible 26 cases. Therefore, one-way ANOVA of treatments was presented. There were significant differences between wetland sites for 6 of the 13 soil variables (Table 1). There were also large site differences in Al, but the means were not significantly different as a result of the large variance for the North Grays Creek site (Table 1). Soils at Cypress Creek had significantly higher pH and concentrations of Ca, Mg, and Na than the other five sites. Round Bay soils had significantly higher P concentrations than the other sites and significantly higher K than all sites except Cypress Creek. The mean soil P concentration was lowest at Cypress Creek, but the difference was only significant when compared with Round Bay and Angel's Bog (Table 1).

#### Within-wetland comparisons

Soils in the forested areas were drier (MOIST) and had less OM and significantly lower concentrations of N and Na (Table 1). There were no within-wetland differences for the other nine variables.

Differences between sites and habitats clearly emerged using discriminant analysis. For bog habitats (Fig. 1, top), Cypress Creek soils separated from the other sites on the first discriminant function axis, which was strongly influenced by high correlation coefficients for Na, pH, Ca, P, and Mg. North Grays Creek, South Grays Creek, Angel's Bog, and Eagle Hill occupied similar positions in the discriminant plot, while Round Bay separated on the second discriminant axis, which is primarily influenced by high correlation coefficients for K, Mg, OM, N, and P.

Round Bay and Cypress Creek forest soils also clearly separated from the other sites (Fig. 1, bottom), but the discriminant functions were much simpler, with P having the largest correlation coefficient for both discriminant functions.

### Plant tissues

Results of the analysis of plant tissues for wetlands (sites), habitats (forest versus bog), and tissue type (woody versus herbaceous) are summarized in Table 2. Similar to the soil data, significant two- and three-way interaction effects for plant tissues are not summarized because there were only 11 significant interactions of a possible 60.

#### Between-wetland comparisons

There were significant site differences for all variables except S, B, Zn, and Si (Table 2). Leaves of Cypress Creek plants had significantly higher concentrations of Sr, Pb, and Mg. Plants at Round Bay had significantly higher concentra-

TABLE 1. Percentages and concentrations for soil parameters

| | % MOIST | % OM | % P | % N | $NO_3$-N | $NH_4$-N |
|---|---|---|---|---|---|---|
| | | | Site | | | |
| Cypress Creek | 83.3±1.2 | 59.4±5.0 | 0.07±0.01*c* | 1.59±0.13 | 0.76±0.05*a* | 66.7±13.7 |
| Round Bay | 85.3±7.7 | 67.1±2.7 | 0.24±0.03*a* | 1.53±0.10 | 0.35±0.06*b* | 71.7±19.5 |
| Angel's Bog | 85.3±1.1 | 70.5±4.0 | 0.13±0.02*b* | 1.92±0.23 | 0.37±0.11*ab* | 117.5±32.3 |
| North Grays Creek | 79.1±2.9 | 63.0±6.3 | 0.09±0.01*bc* | 1.22±0.11 | 0.49±0.10*ab* | 58.1±14.1 |
| South Grays Creek | 78.7±3.5 | 63.9±6.4 | 0.09±0.1*bc* | 1.67±0.14 | 0.55±0.11*ab* | 75.1±16.8 |
| Eagle Hill | 84.7±1.2 | 66.3±4.3 | 0.11±0.01*bc* | 1.69±0.17 | 0.48±0.08*ab* | 64.8±14.8 |
| | | | Habitat | | | |
| Forested | 79.5±2.1*a* | 59.3±3.9*a* | 0.14±0.02 | 1.41±0.09*a* | 0.52±0.05 | 66.1± 8.7 |
| Bog | 84.5±0.7*b* | 68.2±2.2*b* | 0.10±0.01 | 1.69±0.07*b* | 0.50±0.05 | 75.8±10.5 |

NOTE: Values are means ± 1 SE. For site and habitat comparisons, means that are not significantly different are followed by the same letter. Letters are extractable $NH_4$-N and $NO_3$-N are in micrograms per gram. Extractable Al and Fe are in milligrams per gram.

TABLE 2. Tissue nutrient concentrations

| | % N | P | % K | % Ca | % MG | % S |
|---|---|---|---|---|---|---|
| | | | Site | | | |
| Cypress Creek | 1.61±1.07*ab* | 0.09±0.00*b* | 1.18±0.08*ab* | 0.83±0.05*ab* | 0.43±0.04*a* | 0.18±0.01 |
| Round Bay | 1.37±0.07*b* | 0.16±0.01*a* | 1.40±0.14*a* | 0.88±0.08*a* | 0.25±0.02*b* | 0.18±0.01 |
| Angel's Bog | 1.23±0.07*b* | 0.12±0.01*b* | 0.81±0.52*c* | 0.85±0.06*ab* | 0.26±0.03*b* | 0.13±0.01 |
| North Grays Creek | 1.70±0.08*a* | 0.10±0.00*b* | 0.95±0.07*bc* | 0.63±0.04*bc* | 0.26±0.02*b* | 0.17±0.01 |
| South Grays Creek | 1.64±0.06*a* | 0.10±0.01*b* | 1.14±0.11*abc* | 0.16±0.07*abc* | 0.22±0.02*b* | 0.16±0.01 |
| Eagle Hill | 1.74±0.08*a* | 0.11±0.08*b* | 1.04±0.09*bc* | 0.57±0.05*c* | 0.26±0.02*b* | 0.17±0.01 |
| | | | Habitat | | | |
| Forested | 1.84±0.05*a* | 0.12±0.00*a* | 1.41±0.08*a* | 0.87±0.05*a* | 0.33±0.02*a* | 0.17±0.01 |
| Bog | 1.39±0.03*b* | 0.11±0.00*b* | 0.90±0.03*b* | 0.67±0.03*b* | 0.25±0.01*b* | 0.16±0.01 |
| | | | Type | | | |
| Herbaceous | 1.76±0.06*a* | 0.12±0.01*a* | 1.51±0.11*a* | 0.62±0.07*a* | 0.29±0.02 | 0.20±0.01*a* |
| Woody | 1.51±0.03*b* | 0.11±0.00*b* | 0.97±0.04*b* | 0.79±0.02*b* | 0.28±0.01 | 0.16±0.01*b* |

NOTE: Values are means ± 1 SE. Means that are not significantly different for each category are followed by the same letter. Letters are not included when there was not

tions of P. There were no other distinct between-site patterns for any of the other variables.

*Within-wetland comparisons*

There were significant within-wetland differences for 10 of the 15 variables and in every instance, tissue concentrations were higher in the forested habitat (Table 2).

Site and habitat differences were also clearly demonstrated by the discriminant analysis. For bogs (Fig. 2, top), the Atlantic white cedar site (Cypress Creek) was distinct from all others except for a small overlap between it and Eagle Hill. Angel's Bog and Round Bay formed a second distinct group, while North Grays Creek, South Grays Creek, and Eagle Hill formed a third grouping. Phosphorus and S had the largest correlation coefficients on the first discriminant function, while Mg and S had the largest coefficients on the second function.

Round Bay and Cypress Creek were distinct from the other sites when forests were compared (Fig. 2, bottom), Magnesium had the highest correlation coefficient on both discriminant functions. S and P also had high correlation coefficients on the first and second functions, respectively.

*Comparisons of tissue types*

Patterns in nutrient concentrations between woody and herbaceous species were not as clear as differences between habitats, even though there were significant differences for 12 of the 15 variables (Table 2). Herbaceous species had significantly higher concentrations of N, P, K. S, Fe, and Si but significantly lower concentrations of Ca, Mn, Cu, B, Sr, and Pb.

Figure 3 is a comparison of tissue nutrient concentrations of plants at the *Chamaecyparis* site with the same species at the other sites. This comparison includes all species sampled except *Chamaedaphne, Symplocarpus,* and *Arundinaria*, none of which occurred at the Atlantic white cedar site. *Chamaecyparis* (Ct) had the lowest tissue concentrations of N and highest concentrations of Ca and Pb. All other chemical concentrations for Atlantic white cedar were within the range of values for other species (Fig. 3), although several (Mn, Fe, Al, and Si) were at the upper end of the range and P, K, and B were at the lower end. Most species had high tissue concentrations of all elements, except P, at the Cypress Creek site.

Among the herbs, *Osmunda* had the highest concentrations of N, K, Ca, Mg, Mn, and Al. *Rhynchospora* had the highest Fe concentrations and the lowest concentrations for all other elements except Mn. *Triadema* had the highest concentrations of B and Cu.

Among the woody species, *Decodon* had the highest concentrations of P, except at Cypress Creek, and of Fe. *Clethra* had the highest concentrations of K, Mg, S, and Al at Cypress Creek and Zn at all sites. *Vaccinium corymbosum* had the highest tissue concentrations of B at Cypress Creek and low at the six wetland sites and within forest and bog habitats

| Ca | Mg | K | Na | pH | Fe | Al |
|---|---|---|---|---|---|---|
| | | | Site | | | |
| 1808±317*a* | 1418±182*a* | 1054±193*ab* | 841±117*a* | 5.34±0.11*a* | 6.29±0.78 | 8.0±1.2 |
| 339± 43*bc* | 493± 27*b* | 1622± 96*a* | 134± 8*de* | 4.23±0.07*b* | 5.93±0.44 | 5.4±1.8 |
| 1169±839*b* | 333± 79*bc* | 745±104*bc* | 404± 39*b* | 4.17±0.22*b* | 5.70±0.60 | 6.5±2.0 |
| 569±105*b* | 227± 30*c* | 543± 75*c* | 286± 39*bc* | 4.69±0.12*b* | 5.19±0.29 | 12.4±5.5 |
| 468± 75*bc* | 262± 33*c* | 693±125*bc* | 198± 26*cd* | 4.31±0.14*b* | 4.80±0.23 | 4.0±1.1 |
| 179± 17*c* | 211± 27*c* | 441± 44*c* | 89± 6*e* | 4.37±0.12*b* | 5.45±0.45 | 5.6±0.5 |
| | | | Habitat | | | |
| 706±168 | 517±107 | 860±125 | 213± 39*a* | 4.54±0.10 | 5.71±0.39 | 6.4±1.2 |
| 710±154 | 477± 69 | 857± 73 | 383± 53*b* | 4.54±0.09 | 5.41±0.20 | 7.6±1.9 |

not included when there was no overall site or habitat difference. MOIST, OM, P, and N values are in percent. Exchangeable Ca, Mg, K, and Na and

summarized by site, habitat, and tissue type

| Mn | Fe | Cu | B | Al | Zn | Sr | Pb | Si |
|---|---|---|---|---|---|---|---|---|
| | | | | Site | | | | |
| 432±36*a* | 336±38*a* | 6.69±0.36*a* | 40.7±3.0 | 174±16*a* | 53.5±5.9 | 59.8±6.2*a* | 178±2.9*a* | 390±18 |
| 284±31*b* | 119±31*b* | 5.69±0.27*ab* | 34.0±1.9 | 112±11*ab* | 35.5±5.6 | 33.1±4.4*b* | 6.6±0.4*b* | 352±21 |
| 301±32*ab* | 140±21*b* | 6.37±0.44*a* | 32.7±2.9 | 80±10*b* | 45.3±7.4 | 28.1±4.0*b* | 7.8±0.7*b* | 279±32 |
| 264±32*b* | 315±56*a* | 7.41±0.48*a* | 33.8±2.4 | 115±11*ab* | 53.0±9.0 | 28.9±3.5*b* | 8.1±0.8*b* | 339±23 |
| 292±30*ab* | 353±64*a* | 5.16±0.36*b* | 36.8±2.8 | 147±23*ab* | 42.5±6.2 | 35.8±4.5*b* | 6.6±0.4*b* | 348±21 |
| 283±35*b* | 355±68*a* | 6.40±0.43*ab* | 33.1±2.3 | 112±11*b* | 48.8±7.2 | 31.2±3.8*b* | 7.6±0.8*b* | 335±20 |
| | | | | Habitat | | | | |
| 386±26*a* | 268±28 | 6.67±0.28 | 40.3±1.9 | 163±21*a* | 52.1±5.2 | 46.6±3.8*a* | 11.2±1.3*a* | 403±12*a* |
| 264±15*b* | 294±32 | 5.99±0.21 | 32.5±1.2 | 105± 6*b* | 43.0±3.2 | 30.9±2.1*b* | 8.1±0.7*b* | 307±12*b* |
| | | | | Type | | | | |
| 274±25*a* | 497±70*a* | 4.59±0.29*a* | 26.1±2.1*a* | 150±31 | 35.7±2.1 | 34.6±4.2*a* | 8.0±0.9*a* | 426±12*a* |
| 327±17*b* | 209±13*b* | 6.72±0.19*b* | 39.0±1.2*b* | 120± 6 | 50.5±3.7 | 38.2±2.3*b* | 9.8±0.8*b* | 317±11*b* |

any significant site, habitat, or type effect. Means are given as percentages (N, P, K, Ca, Mg, S) or micrograms per gram (Mn, Fe, Cu, B, Al, Zn, Si).

concentrations of K, N, P, Mg, and Zn. *Acer rubrum* and *V. macrocarpon* had the lowest tissue concentrations for S and Al, but there was no discernable pattern for any of the other elements. *Magnolia* had the lowest concentrations of N, Sr, and Cu.

## Discussion

Several patterns emerged from this study. Atlantic white cedar wetlands appear to have a distinct soil and plant chemistry and some nutrients may be limiting to Atlantic white cedar and other species. Calcium is higher in tissues of *Chamaecyparis* and there is evidence to suggest that it concentrates heavy metals more than other species.

Less than half of the soil variables showed significant differences between sites and these were only within-wetland differences for two of the nutrients (N and Na) (Table 1). Nonetheless, the *Chamaecyparis* site had a distinctive soil chemistry (Fig. 1) characterized by high concentrations of Ca, Mg, and Na, high pH, comparatively low P concentrations, and high concentrations of Fe and Al (Table 1). Unfortunately, we know of only a few other data sets that can be used to determine whether or not the differences that we have found are characteristic of other *Chamaecyparis* sites. The high pH at the Maryland site is most likely due to flooding with brackish estuarine water, which has a high pH. The pH range measured at Maryland site thus extends the range of pH conditions reported for *Chamaecyparis* by Day (1984). Clewell and Ward (1987) recently report that isolated populations of *Chamaecyparis* in northern Florida are found at sites with pH ranging from 6.6 to 7.5. Golet and Lowry (1987) also recently noted a higher groundwater pH (4.95 and 4.26) in some Rhode Island *Chamaecyparis* stands compared with those measured in the Great Dismal Swamp in Virginia (Day 1984). Golet and Lowry found higher maximum growth rates of *Chamaecyparis* at sites with pH higher than 4.0 compared with sites with a pH less than 4.0. Atlantic white cedar sites thus occur over a wider range of pH conditions than has been previously reported. We can only speculate that stands develop in areas with higher pH and that low pH conditions are associated with peat formation during stand development.

Compared with soils, leaf tissues showed many significant differences between sites, within wetlands, and between tissue types. These differences are most likely an expression of differential uptake of nutrients by wetland plant species (Tamm 1954, 1964; Epstein 1972; Van Den Driessche 1974; Kabata-Pendias and Pendias 1984), even though the growth medium usually has the greatest influence on elemental concentrations in plant tissues.

Tissue and soil concentrations at the *Chamaecyparis* site

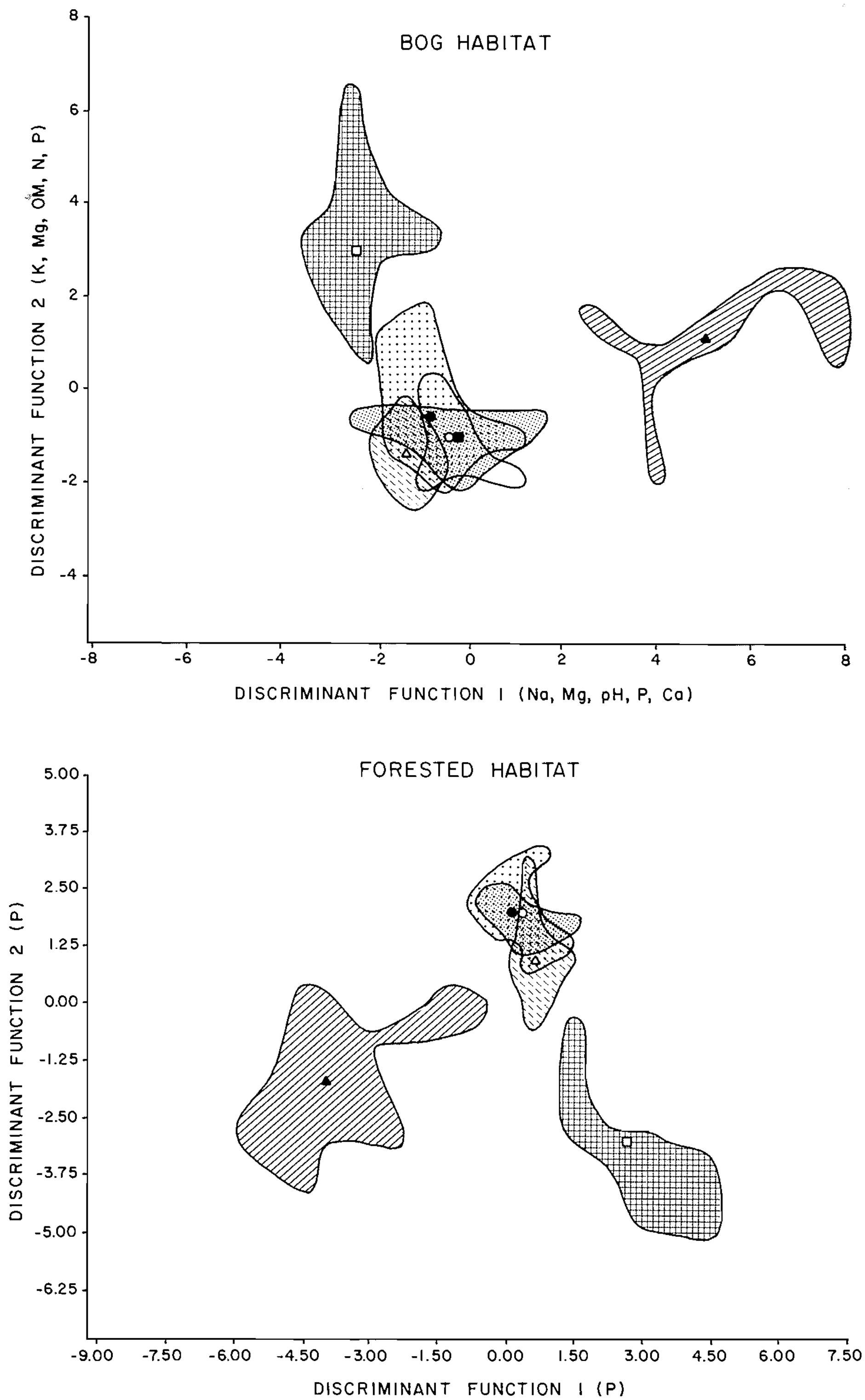


FIG. 1. Discriminant analysis of soil data for bog (Fig. 1, top) and forest (Fig. 1, bottom) habitats at the six Maryland sites. The position of each site along the first two axes is indicated by ▲, Cypress Creek; □, Round Bay; △, Eagle Hill; ○, North Grays Creek; ●, South Grays Creek; ■, Angel's Bog. Fields of distributions for samples within each site are enclosed by a continuous line. Variables with high correlation coefficients for the first two discriminant functions are given on the *x*- and *y*-axes for both habitats.

showed parallel trends for some elements. Leaves of species at that site had significantly higher Ca, Mg, and Al and low P (Table 2; Fig. 3). Soils also had significantly high Ca and Mg and low P. The low leaf P and high Al content is most likely due to the high P adsorption capacity of these soils, which has been related to their high extractable Al content (Richardson 1985). High concentrations of Pb in tissues at the *Chamaecyparis* site are most likely due to the wetlands proximity to a busy highway (Siccama and Porter 1972) and they are well above the levels needed by plants (Kabata-Pendias and Pendias

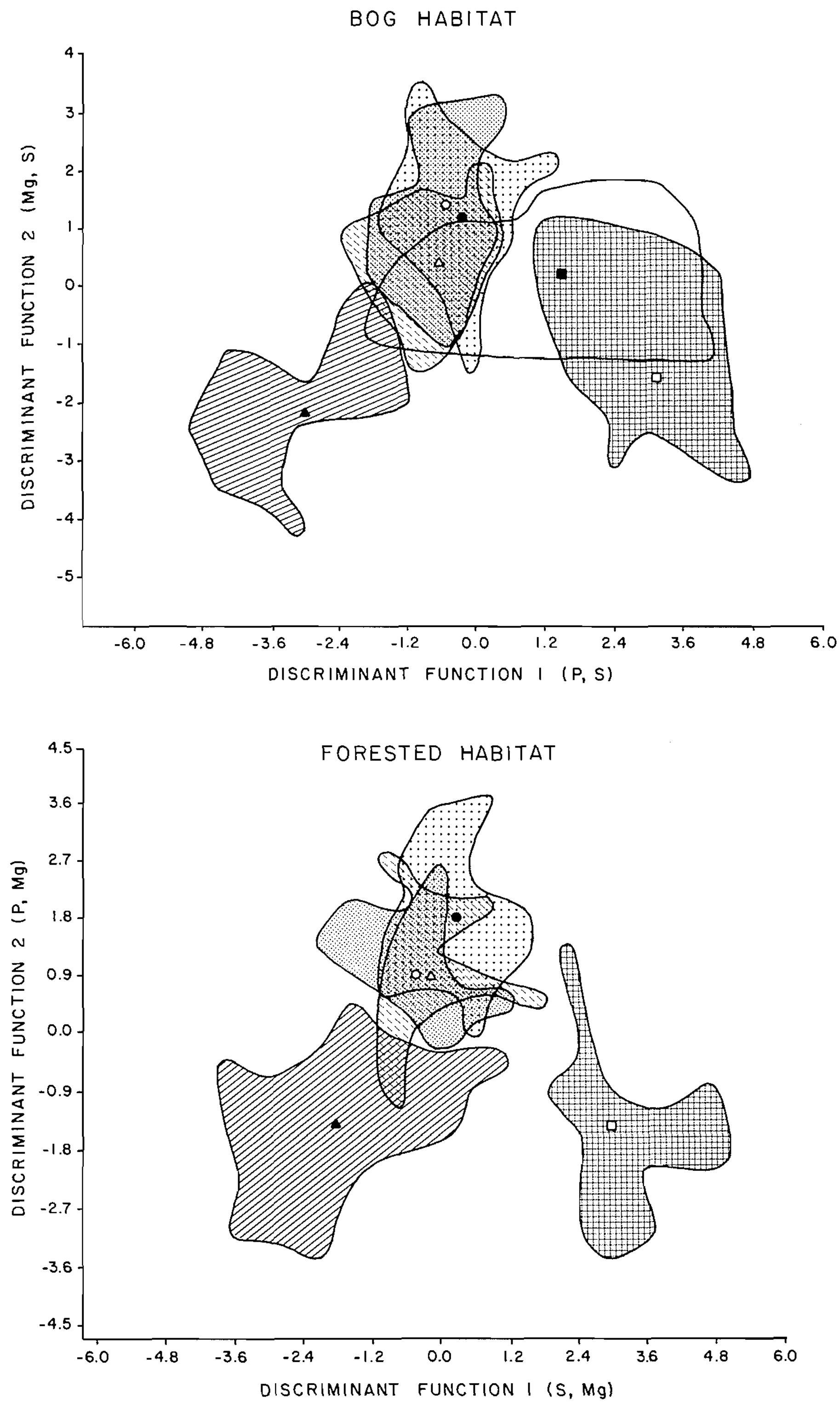


FIG. 2. Discriminant analysis of plant tissue data for the bog (Fig. 2, top) and forest (Fig. 2, bottom) habitats at the six Maryland sites. The position of each site along the first two axes is indicated by symbols as given in Fig. 1. Fields of distributions for samples within each site are enclosed by a continuous line. Variables with high correlation coefficients for the first two discriminant functions are given on the *x*- and *y*-axes for both habitats.

1984). Of the species sampled, *Chamaecyparis* had higher Pb concentrations than any other species (Fig. 3). High concentrations of Fe and Sr may also be related to its proximity to the highway and estuary. Sr concentrations may be associated with flooding by brackish water since large amounts of Sr are precipitated with carbonates in estuarine areas. Iron concentrations are also high in estuarine water and in runoff from the highway. Although the high Ca concentrations of *Chamaecyparis* may be related to the fact that the wetland is sometimes flooded with estuarine water, Bandle and Day (1985)

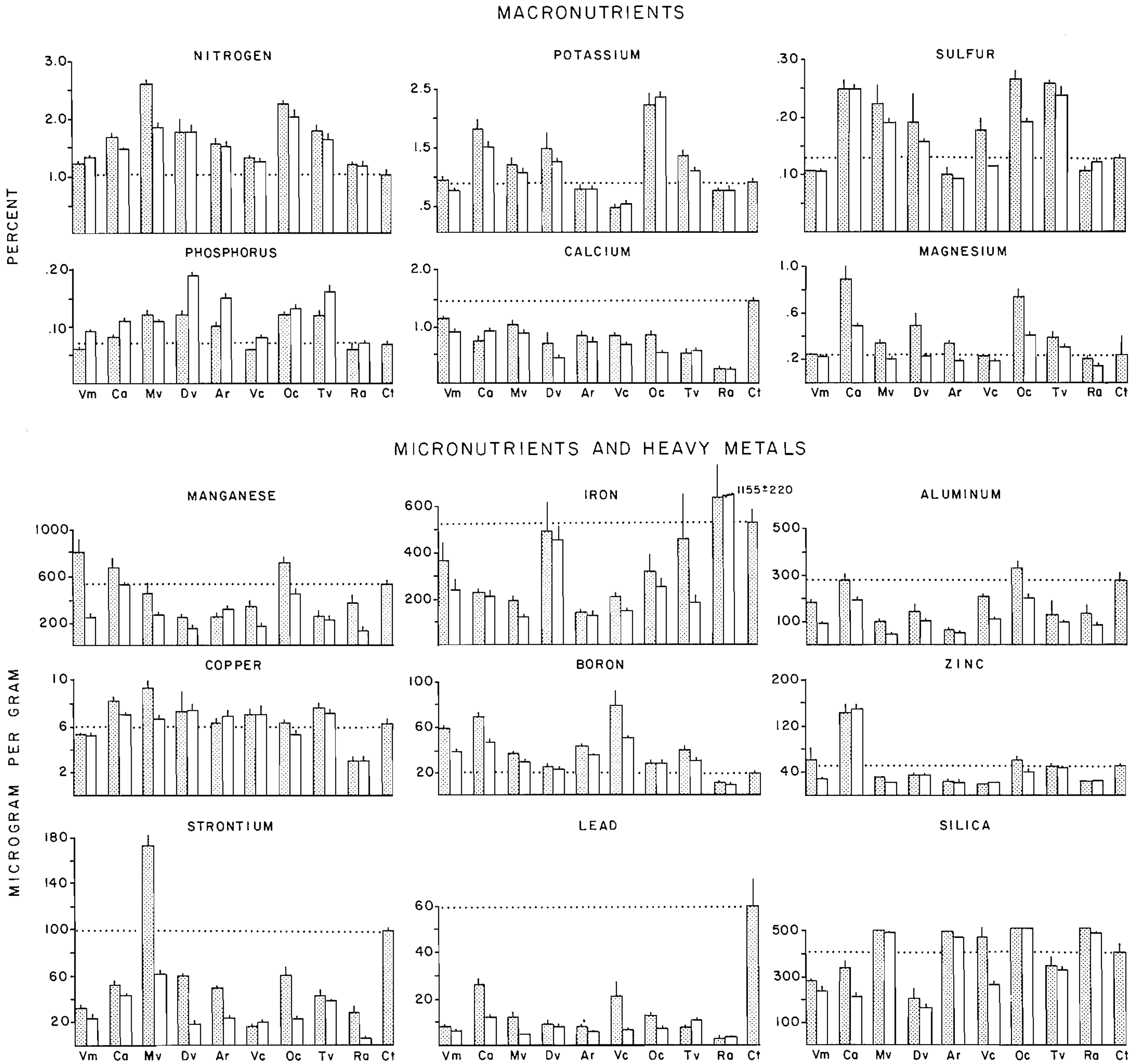


FIG. 3. Mean leaf concentrations of elements and nutrients for 10 species at the six Maryland sites. Means for the *Chamaecyparis* site are the stippled bars, while means for the other five sites are the open bars. Ct, *Chamaecyparis thyoides*; Mv, *Magnolia virginiana*; Ar, *Acer rubrum*; Vm, *Vaccinium macrocarpon*; Ca, *Clethra alnifolia*; Dv, *Decodon verticillatus*; Vc, *Vaccinium corymbosum*; Oc, *Osmunda cinnamomea*; Tv, *Triadenum virginicum*; Ra, *Rynchospora alba*. For comparison, the dotted line in each figure is the value for *Chamaecyparis*. Means (±1 SE) for N, P, K, Ca, S, and Mg are in percent. Means for the other elements are in micrograms per gram.

also found significantly higher Ca in *Chamaecyparis* in the Great Dismal Swamp, where the soils had high exchangeable Ca. Our *Chamaecyparis* site was also higher in exchangeable Ca than were the other sites (Table 1).

Reasons for the many significant within-wetland differences in tissue nutrient concentrations are less clear, but they may be due to the fact that substrates in the forested habitats contained less moisture and lower OM content (Table 1), suggesting that soils in these sites may be more oxidized, allowing plants to assimilate nutrients more efficiently. Bandle and Day (1985) found similar soil and plant tissue relationships in the Great Dismal Swamp, where *Chamaecyparis* stands were the second driest of the forested wetlands studied. Their data also suggest that water-level fluctuations may be greater in forested areas and that nutrients may be more available at those sites.

Our study and that of Bandle and Day (1985) in Virginia suggest that some nutrients may limit plant growth in *Chamaecyparis* stands. A comparison of tissue nutrient concentrations of *Chamaecyparis* and *Acer rubrum* at the Virginia and Maryland sites shows similar August levels for Ca, Mg, and N, but *Chamaecyparis* at our site had only 50% of the P values found at the Great Dismal Swamp (Table 3). The low concentrations of P at both sites suggest that P may be a limiting nutrient, since it is below the suggested minimum value for plants

TABLE 3. A comparison of August nutrient content (percent dry weight) in leaves of *Chamaecyparis thyoides* and *Acer rubrum* from Maryland and Virginia Atlantic white cedar sites. The values from Epstein (1972) are given as an indication of minimum concentrations needed for adequate growth

| Species | Source | Location | N | P | K | Ca | Mg |
|---|---|---|---|---|---|---|---|
| Atlantic white cedar | This study | Maryland | 1.03 | 0.07 | 0.87 | 1.41 | 0.26 |
| Atlantic white cedar | Bandle and Day 1985 | Virginia | 1.20* | 0.14 | 0.57 | 1.33 | 0.25 |
| Red maple | This study | Maryland | 1.58 | 0.10 | 0.78 | 0.83 | 0.33 |
| Red maple | Bandle and Day 1985 | Virginia | 1.88 | 0.09 | 0.54 | 1.06 | 0.23 |
| Minimum value | Epstein | | 1.50 | 0.20 | 1.00 | 0.50 | 0.20 |

*Litter data from October 1978 (Gomez and Day 1982).



(Table 3). Potassium may also be limiting at both sites for both species (Table 3). At the Maryland site, K concentrations were nearly twice those found at the Great Dismal Swamp, a pattern that coincides with much higher exchangeable soil K values at our site, but the levels were low compared with concentrations that have been suggested as being minimal for growth (Epstein 1972). *Acer rubrum* does not appear to be N limited (Table 3) at the Maryland and Virginia sites, but *Chamaecyparis* concentrations were below the minimum required for growth and maintenance as suggested by Epstein (1972). Neither Mg nor Ca appear to be limiting at the two sites (Table 3). Our results thus support those of Tamm (1954, 1964), who suggested that swamp species often grow in areas with suboptimal concentrations of available P and K.

The potential nutrient deficiencies at the Maryland and Virginia sites may be associated with nutrient-poor soils on the coastal plain. Extensive areas of wetland soils deficient in P have been identified on the southeastern coastal plain (Ralston and Richter 1980) and coniferous species have been shown to respond positively to P fertilization on coastal plain soils (Terry and Hughes 1975). Also, soils with low P levels and high P retention, like our *Chamaecyparis* site, have been shown to not provide adequate P for optimum tree growth (Wells et al. 1973).

## Conclusions

Our study indicates that *Chamaecyparis* sites have a distinct soil and plant chemistry and the results were similar to those found for a *Chamaecyparis* site in Virginia (Bandle and Day 1985). Although there are soil and plant chemical data for very few sites, there is a strong indication that *Chamaecyparis* may be restricted to sites with high soil Ca, Mg, and Al and that N, P, and K may be limiting nutrients. Similarly, the accumulation of Ca by *Chamaecyparis* seems to be characteristic for the two sites studied thus far. *Chamaecyparis* also appears capable of accumulating more Pb than other species. This study and those from the Great Dismal swamp have provided some initial characterization of plant and soil chemistry of *Chamaecyparis* wetlands. Clearly much more comparative data are needed to characterize species requirements and limitations from a wide range of sites over the species range, which is from Maine to Florida (Laderman 1987).

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