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ELEMENT MOBILITY IN BALD CYPRESS XYLEM

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ABSTRACT

Trace element mobility in bald cypress (*Taxodium distichum*) was investigated for a suite of elements using cores from century-old trees from a wetland in Humphreys County, Mississippi. Element mobility was determined by comparing the dendrochemistry of decadal increments over the life span of a tree, and by comparing increments of the same age collected from the same tree during two different seasons. Variability within growth increments at the time of sampling was evaluated by comparing cores from the same tree collected at three points around the bole. Of 42 elements analyzed, eight were found above detection limits (As, Ca, K, Mg, Mn, Na, P, Zn). Clear evidence of translocation of P and Mn to the sapwood and K, Mg, and Na to the heartwood was observed. Ca and Zn were found with higher average concentrations in the sapwood, though evidence of translocation to the sapwood was equivocal. Arsenic did not vary significantly through any individual core. Variation in concentration was not found to be significant for any element with respect to year of sampling, season, location in the wetland, or position around the bole. With the exception of As, variation was significant with respect to increment age (decade) and location within the heartwood or sapwood.

Keywords: bald cypress, dendrochemistry, xylem chemistry.

INTRODUCTION

Numerous studies have documented a record of historical changes in environmental chemistry preserved in the annual growth increments of trees and have been incorporated into dendrochemical studies worldwide (Cutter and Guyette 1993). The ability of a tree to preserve a chemical record of historical inputs to the ecosystem is dependent on a number of variables related to tree physiology; not all species respond the same. According to Cutter and Guyette (1993) the optimal species used in dendrochemical investigations should have longevity, widespread distribution, a distinct heartwood-sapwood boundary, few sapwood increments, and low heartwood moisture and permeability. Smith and Shortle (1996) suggest additional considerations such as selection of trees free of injury or infection, and advocate knowledge of element transport pathways and whether certain elements are preferentially absorbed or excluded in the root zone. Bald cypress trees were not recommended by Cutter and Guyette (1993) because of the high moisture content and large number of sapwood rings, both of which may facilitate the radial translocation of elements across annual increments. However, bald cypress have considerable longevity, widespread distribution, and thrive in habitats unfavorable to the species rated more highly. Bald cypress can grow in partially and fully inundated wetland environments, which often serve as sinks for anthropogenic chemicals discharged to the environment (Kitchens *et al.* 1975; Phillips 1989).

Although the physiological characteristics of bald cypress might be less than ideal, a few studies have been successful in using bald cypress dendrochemistry to document changes in wetland chemistry. Latimer *et al.* (1996) successfully correlated the operation of a Louisiana refinery and subsequent dredging with Pb and Zn levels in bald cypress ring increments. Yanosky *et al.* (1995) observed translocation of Cl to the heartwood of

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bald cypress in response to seawater intrusion, but were able to estimate the timing of intrusion based on the number of heartwood rings bearing elevated Cl. Nutrient partitioning in seedlings has also been studied (Dickson *et al.* 1972), but little else is known about the behavior of most trace elements in mature bald cypress, or the degree to which bald cypress accurately record changes in historical chemical fluxes. This investigation documents the behavior of a suite of elements in bald cypress in an effort to determine their suitability for dendrochemical studies, particularly in wetlands.

Study Site

Sky Lake (Figure 1) is an abandoned oxbow of the ancient Mississippi-Ohio river system, located in northern Humphreys County, Mississippi. The lake is bordered by a riparian fringe ranging up to 1 km in width, and surrounded by land cleared for agricultural use toward the end of the 19th Century. The area of study lies along the northern margin of the lake and includes two ecologically similar areas, designated here as the eastern and western areas. The eastern area is 10 to 20 cm higher in elevation and accumulates sediment at a lower rate than the western area (eastern: ~3 mm/yr; western: ~10 mm/yr; Davidson *et al.* 2004). The lake receives runoff from 1,862 ha (4600 ac) of predominantly agricultural land through several drainage systems and overland flow. The riparian fringe is typically inundated during the winter months.

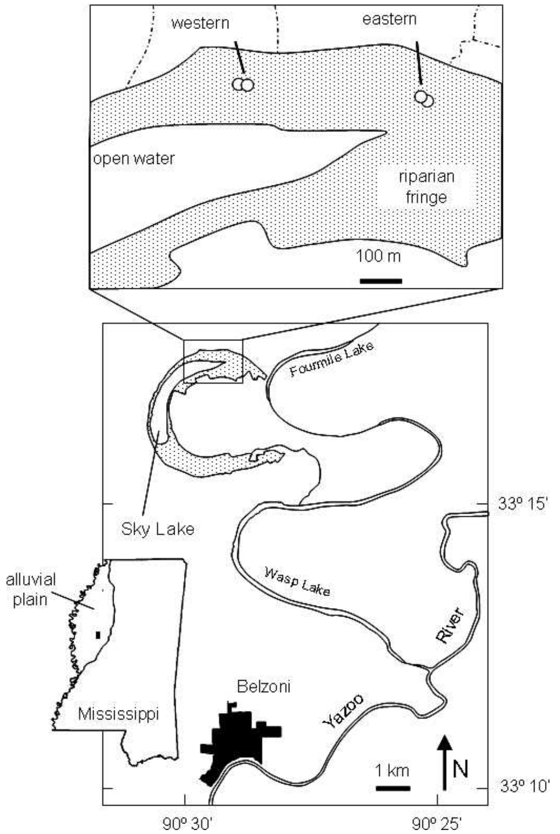

Figure 1. Location map with eastern and western tree locations at Sky Lake. Shaded areas are riparian fringe; dashed lines designate ephemeral or semi-perennial streams. The inset outline of the state of Mississippi shows the boundary of the alluvial plain (ancestral floodplain of the Mississippi River) and location of the enlarged map.

METHODS

A dendrochronology for the stand of bald cypress on the northern margin of Sky Lake was established using 0.5 cm increment cores from 103 trees. Ring increment width was measured using a binocular microscope fitted with an ocular micrometer. Profiles were crossdated to account for missing or false rings. (Galicki 2002). All were inspected for visible heartwood-sapwood boundaries; 12 were analyzed for xylem density (0.5 cm cores). Four dominant 100-year old trees without heart rot were selected for moisture content and detailed dendrochemical analyses: two from the western area and two from the eastern area.

Of the four trees selected for dendrochemical study, one tree from each area was cored in February, and again in May, 2000. Cores from a second tree in each area were collected in February and May, 2003. There was no foliage on the trees in February, but by the May sampling the development of the canopy was complete. Cores were collected above the buttress to minimize problems with false or missing rings. On each sampling date, a minimum of six 1.2 cm diameter cores were collected: two cores from three different sides of the tree (0° (north), 120°, and 240°). Cores were collected in pairs to increase the sample weight submitted for chemical analyses.

Table 1. Element detection limits for elements at or below the detection limit, and concentration range for elements above the detection limit.

Near or Below Detection Limit				Suitable for Investigation		
Element with Detection Limit (ppm)				Element	D.L.	Range (ppm)
Ag	0.30	Nd	0.03	Al*	1	3–94
Au	0.10	Ni	2	As	0.01	0.01–0.70
Ba	5.00	Pb	1	Br*	0.01	0.3–0.64
Ce	0.10	Rb	1	Ca	100	100–3,200
Co	0.10	Sb	5	Cl*	3	17–164
Cr	0.30	Sc	0.1	K	100	290–4,340
Cs	0.05	Se	0.1	Na	1	8–430
Cu	1.00	Sm	0.001	Mn	0.01	0.40–16.90
Eu	0.05	Sr	0.1	Mg	1	21–709
Fe	50	Ta	0.05	P	0.05	1.00–230
Hf	0.05	Tb	0.1	Zn	2	1–59
Hg	0.05	Th	0.1			
Ir	0.10	U	0.01			
La	0.10	W	0.05			
Lu	0.001	Yb	0.005			
Mo	0.05					

* Nonreproducible data

Cores were sealed individually in plastic bags immediately after recovery from the increment borer for transport to the lab and immediate weighing. All cores were divided based on the position of the heartwood-sapwood boundary and weighed prior to drying in a lab oven. The cores were surfaced using 600 grit sandpaper and sectioned into 10 decadal increments (beginning with 1898 and sampling through 1997) based on ring increment correlation with a previously dated 0.5 cm core from the same tree. The sampling interval was chosen to accommodate the oldest ring increments in the selected trees. Equivalent decadal increments from paired cores taken from the same side of each tree were combined for chemical analysis. This yielded 3 samples per decade for each tree cored.

Decadal samples were analyzed by Instrumental Neutron Activation (INA) and Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) for 42 elements (Table 1). Samples for INA analysis were dried, macerated in a Wiley mill, compressed to form a briquette and irradiated (Hoffman 1992). Samples analyzed using ICP-OES were first ashed at 475°C over a 24 hour period, and then digested with aqua regia for 2 hours at 95°C. Analytical precision was based on the value of element concentrations relative to the detection limit; values ranged from ±100% at the detection limit to ±5% at 100 times the detection limit. All samples were run simultaneously with National Institute of Science and Technology (NIST), or in-house lab standards.

Moisture content was determined using an initial weight of a sealed core, taken within 5 hours of sampling, and the weight after drying at 80°C until no additional loss in weight was detected. The moisture content was calculated as a percent water mass relative to the mass of the dry core (Simpson and TenWolde 1999). Xylem density was calculated on decadal increments using the measured volume and dry weight.

The sampling strategy produced a data set with a hierarchical structure of parameters suitable for statistical analysis using a Bonferroni adjusted level of significance (alpha = 0.0083) to identify significant variations in trace element concentrations relative to each of the sample parameters. The hierarchical structure considered four trees, divided into decadal increments (age) and location relative to the heartwood-sapwood boundary (H-S boundary), with each tree sampled during February and May (season), from three locations around the bole (direction), and with

Table 2. Average element concentrations, moisture content, and xylem density for bald cypress at Sky Lake. Sapwood/heartwood moisture content – six cores from two trees; density – 221 decadal increments from 12 trees; chemical compositions – 240 decadal increments from four trees.

	Element Concentrations (ppm)		
	Average Xylem	Heartwood	Sapwood
P	48 ± 15	9 ± 4	105 ± 32
Mn	2.3 ± 1.0	1.5 ± 0.7	3.4 ± 1.5
Zn	6.1 ± 2.1	5.0 ± 2.3	7.6 ± 1.7
Ca	1,342 ± 322	1,270 ± 271	1,449 ± 399
Mg	289 ± 58	327 ± 65	231 ± 48
K	1,345 ± 469	1,544 ± 481	1,046 ± 451
Na	150 ± 76	181 ± 75	104 ± 76
As	0.12 ± 0.08	0.13 ± 0.08	0.12 ± 0.08
Moisture Content (%)		122 ± 22	149 ± 17
Xylem Density (g/cm^3)		0.38 ± 0.08	0.36 ± 0.05

two of the trees sampled in 2000 and two in 2003 (year) in two different sampling areas each year (location). A total of 240 decadal increments (four trees, ten decades per tree, and six cores per decade) were analyzed for elemental composition.

RESULTS

Heartwood-Sapwood Boundary, Density, and Moisture Content

The heartwood-sapwood boundary is commonly determined by the change in color from light to dark when examining the core from the bark to the center (Brown 1984; Cutter and Guyette 1993). The boundary is not always obvious and cannot be determined on many trees. A clear boundary was observed in this study in 54 out of 103 cores. The average sapwood interval was 27±9 yr (1σ) with no statistical distinction observed between trees in the western and eastern areas. No variation in the boundary position was observed around the bole in trees where multiple cores were available. The sapwood interval for the four trees selected for dendrochemical analysis was 25 years (western) and 41 years (eastern) for the two with clear heartwood-sapwood boundaries, and estimated at approximately 46 years (western) and 50 years (eastern) for the two with a less apparent heartwood-sapwood boundary.

Whole-core moisture content ranged from 83% to 149% (based on 24 cores from 4 trees). Where a clear boundary could be identified between heartwood and sapwood, the moisture content was slightly higher in the sapwood. In 12 cores taken from two trees, the average moisture content was 149±17% for sapwood and 122±22% for heartwood (Table 2). There was no significant difference in seasonal moisture content within either the sapwood or heartwood intervals (t-test, $p>0.05$).

The dry bulk density of bald cypress xylem ranged from 0.23 g/cm^3 to 0.76 g/cm^3, with a mean of 0.37±0.08 g/cm^3 (221 decadal intervals measured from 12 trees). There was no significant difference between the dry bulk density of the heartwood and sapwood (t-test, $p>0.05$).

Bulk Dendrochemistry

Thirty-one of the 42 trace elements investigated were near or below the analytical detection limit and excluded from further study. Of the 11 elements above detection, Al, Br and Cl data could not be replicated in duplicate analyses and were excluded from this discussion. The remaining elements investigated were As, Ca, K, Na, Mg, Mn, P, and Zn. Table 1 displays the detection limits and concentration range for each of the elements analyzed. Based on dry weight percentages, the elements investigated comprise 0.3±0.1% of the xylem mass. Of the eight elements, Ca and K maintained the highest concentrations, followed in decreasing order of abundance by Mg, Na, P, Zn, Mn and As (Table 2).

Decadal Dendrochemistry, and Seasonal and Radial Variability

Each sampling produced three concentrations for each element in each decade of growth (sampling from three sides of the tree). The year in which a tree was sampled, its location in the riparian fringe, the season in which it was sampled, and the cardinal direction of the cores, did not contribute significantly to the measured values for any of the measured elements (all $p > 0.05$ after Bonferroni correction was applied). Significant variation was associated with the decade in which the section of the core grew and association with the heartwood-sapwood boundary for all elements except As, which showed no pattern associated with any parameter of the sampling structure. An example data set is shown in Figure 2 for two elements (P and Mg) from a single tree.

Trends observed in xylem element concentration profiles reveal three different patterns: (1) highest concentrations in the sapwood, (P, Mn, Ca, and Zn), (2) highest concentrations in the heartwood (K, Na, and Mg), and (3) no apparent heartwood-sapwood preference (As) (Figure 3).

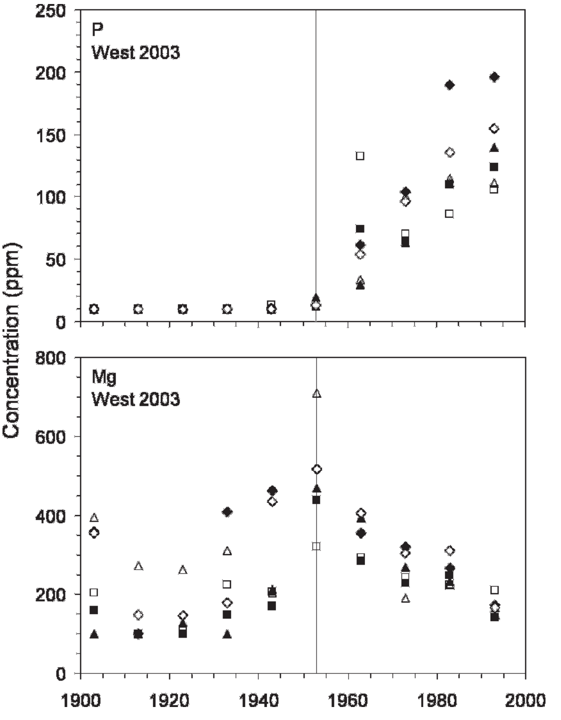

Figure 2. Variation in concentration for two example elements (P and Mg) for different seasons and different positions around the bole from the same tree. Solid symbols – February collection; open symbols – May collection. Triangles – 0° (North); squares – 120°; diamonds – 240°.

DISCUSSION

Higher concentrations in tree rings representing growth in the first or second half of the last century, approximately correlating with the heartwood and sapwood intervals of the four trees sampled, could result from changes in chemical influx during these time periods as well as from translocation. The possibility that changes in concentration in the tree rings were caused by chemical changes in the environment were investigated by comparing the tree-ring results with the concentration of the same elements measured in sediment cores from Sky Lake reported by Galicki (2002) and Galicki *et al.* (in press). A depth-age relationship was determined for sediment cores in these studies using ^{210}Pb and ^{137}Cs, and as many as 32 depth intervals were analyzed for element concentrations within sediments deposited during the last century. A comparison of changes in element concentration in sediment and tree rings as a function of the date of deposition or growth did not reveal any correlation.

In dendrochemistry studies, it is also possible that measured differences in concentration in the heartwood and sapwood could be an artifact of differences in moisture content. If the heartwood and sapwood contain the same concentration of an element dissolved in xylem fluids, the higher moisture content of the sapwood will result in a greater mass of the element in the sapwood when dried and analyzed. Xylem fluids were not directly sampled for this study, but the fact that K, Na and Mg are found in higher concentrations in the heartwood suggests that differences in moisture content do not significantly bias the resulting concentration measurements. Higher concentrations of P, Mn, K, Na, and Mg (and possibly Ca

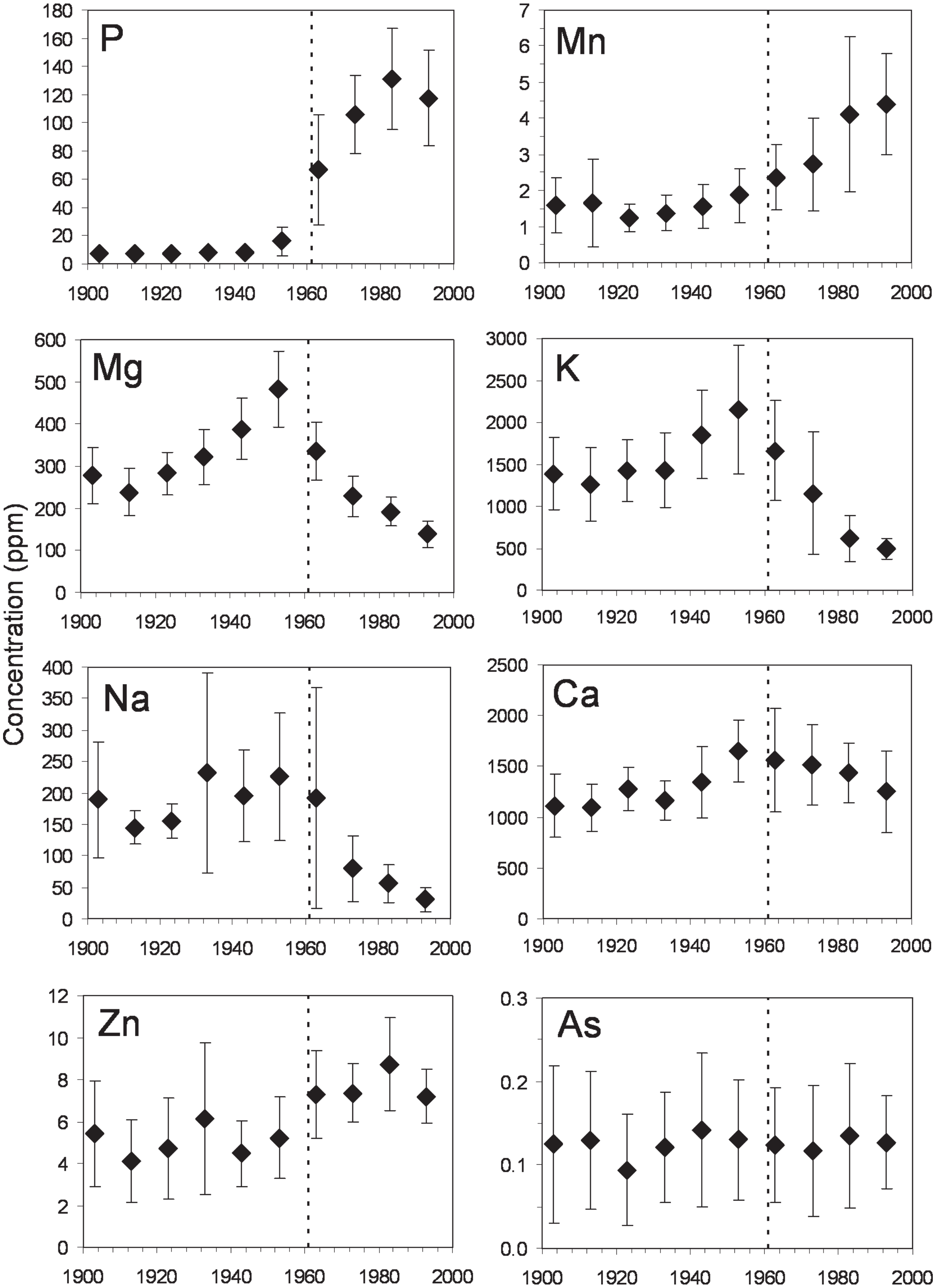

Figure 3. Radial element concentration profiles in bald cypress. Dashed vertical line is the average position of the heartwood-sapwood boundary in the four trees analyzed. Error bars represent one standard deviation about the mean concentration of each element in each decade from all four trees.

and Zn) on one side or the other of the heartwood-sapwood boundary appear to be caused by translocation across growth rings.

Radial Translocation to the Sapwood

Phosphorus and Mn are nutrients that have been previously observed to translocate to the sapwood in other tree species such as white oak (*Quercus alba* L.) and tulip (*Liriodendron tulipifera* L.) (Wardell and Hart 1973; McClenahen *et al.* 1989). Phosphorus is typically a growth limiting nutrient, so it is not surprising to see P exhibit the largest difference between the heartwood and sapwood. Concentrations rise from less than 10 ppm in the heartwood to over 100 ppm in the sapwood. Manganese is considered a micro-nutrient that aids in metabolic processes (Taiz and Zieger 1998); Mn concentrations in the sapwood are twice as high as those in the heartwood.

The average concentrations of Ca and Zn are greater, 12% and 34% respectively, in the sapwood than in the heartwood, but the relatively small difference makes it unclear if this represents translocation. Calcium and Zn have been identified as plant nutrients. Calcium is known to be incorporated into the structural components in cell walls, and Zn assists in electron transfer reactions (Taiz and Zieger 1998). Elevated environmental Ca influxes have been found preserved in tree rings of other tree species such as beech (*Fagus sylvatica*) (Meisch *et al.* 1986), but little is known about Ca retention in bald cypress from previous studies. Latimer *et al.* (1996) did not rule out radial translocation of Zn and Pb in their study of bald cypress, but elevated levels of these metals in rings corresponding to periods of nearby refinery operation and dredging indicate that translocation is limited. For metals such as Zn and Pb, slow rates of radial translocation may allow large increases in uptake to remain measurable for many decades. In this case, care must be taken in interpreting increasing concentrations in tree rings preceding a peak value. The initial rise could reflect the first arrival of a contaminant to the environment, or the rise could reflect gradual radial translocation.

Radial Translocation to the Heartwood

Heartwood radial translocation has been interpreted as a disposal mechanism when environmental element concentrations exceed tolerance limits, or possibly as a storage mechanism of elements for later retrieval. Yanosky *et al.* (1995) interpreted the heartwood radial translocation of chloride in bald cypress tree rings as a method of disposing of excessive chloride concentrations during seawater intrusion into a North Carolina estuary.

The concentrations of K, Mg and Na in the trees from Sky Lake rise significantly from the outer rings toward the heartwood, and peak near the heartwood-sapwood boundary (Figure 3). The increase toward the heartwood is consistent with radial translocation, though it is unclear why the concentrations decline again toward the center of the tree. Similar element profiles across the heartwood/sapwood boundary have been reported for K and Mg by McClenahen *et al.* (1989) and Tout *et al.* (1977), respectively, without suggestions of possible cause.

Potassium, Mg and Na are micro-nutrients employed in enzyme production, phosphate transfer and chlorophyll production, respectively (Taiz and Zieger 1998). At elevated concentrations, all elements can have toxic effects, but little is known about the specific tolerance of bald cypress to these elements. Radial translocation of K, Mg and Na suggests that the water supply contains an excess of these elements necessary for optimum health. Vroblesky *et al.* (1992) observed radial translocation of K to the heartwood in tulip trees growing over a contaminated groundwater with K concentrations above 9 ppm, while trees not influenced by the contaminant plume did not exhibit heartwood radial translocation. In Sky Lake, twice-monthly sampling of surface water over the course of one year produced maximum concentrations for K, Mg and Na of 9.5, 20.5 and 26.4 ppm, respectively (Laine 2004). The K concentrations at Sky Lake are in the same range that was considered a contaminant by Vroblesky *et al.* (1992).

CONCLUSIONS

Bald cypress xylem concentrations of As, Ca, K, Na, Mg, Mn, P and Zn in decadal increments did not vary significantly with sampling year, location within the wetland, season of sampling, or position around the bole. All but As did vary significantly relative to the decade of growth and association with either the heartwood or sapwood. P, Mn, Ca, and Zn concentrations were greatest in the sapwood, and K, Mg, and Na concentrations were greatest in the heartwood. Arsenic concentrations did not vary significantly in any individual tree core. Element concentrations reported in dated sediment cores from Sky Lake did not correlate with increasing or decreasing concentrations observed in the tree cores, which suggests that differences between heartwood and sapwood concentrations reflect translocation rather than changes in the availability of theses elements in the local environment.

The results of this study taken together with previous work by Latimer *et al.* (1996) and Yanosky *et al.* (1995) suggest that bald cypress trees do possess the ability to preserve a record of some changes in chemical influxes to the environment, but translocation across multi-decadal sapwood intervals must be considered possible for most of the elements reported above. The longevity and unique ecological niche bald cypress have in wetlands make them worthy of additional study, particularly in environments where a historical record of contamination can be documented.

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