SPATIAL AND SEASONAL VARIATIONS OF POLLEN IN THE MISSISSIPPI AND ATCHAFALAYA RIVERS, U.S.A.

Alexei Smirnov
Department of Geography
McGill University, Montreal
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ABSTRACT

The objective of this research is to develop a better understanding of the nature of transport and distribution of pollen in river systems. Interpretation of palynological data from sedimentary deposits requires an understanding of processes of pollen transport and deposition. However, research on taphonomic processes in dynamically variable environments, such as rivers, has been limited and inconclusive. The two studies reported here focus on questions arising from previous research, specifically the relationship of pollen concentration and distribution to flow velocity, distance from river bottom, and sediment supply.

The study reported in chapter 1 examines pollen concentrations and velocity data within a cross section of the Mississippi River at St. Francisville, Louisiana, to examine processes of pollen suspension and transport. The profile consists of five verticals sampled at six different depths paired with current velocity measurements, as well as surface samples. Contrary to other reports, no significant correlation between pollen concentrations and flow velocity is found. Application of established theory of suspended particle transport to processes of pollen grain transport demonstrates that such relationships should not be expected in a river. Due to the negligible terminal fall velocities of pollen grains, the theory yields a nearly uniform distribution of pollen load with depth. It is also demonstrated that differential deposition of pollen grains in the fluvial environment is an unlikely phenomenon. Other mechanisms, such as pollen rain and resuspension of grains from the bed, are more likely to explain the non-uniform distribution of pollen in rivers.

To establish potential sources of pollen in fluvially related sediment sequences, one should be concerned with the factors controlling formation of pollen load in a river throughout a year, the focus of chapter 2. This study examines the seasonal distribution of pollen load within a cross section of the Atchafalaya River at Morgan City, Louisiana. The study utilizes three sample events assumed to represent periods with different intensities of pollen production as well as various hydrologic regimes. Data on current velocities collected concurrently with pollen samples allowed for development of pollen discharge estimates for each season. Analysis of suspended pollen in the Atchafalaya

suggests that pollen production by upper basin and local vegetation and processes of movement and storage of sediment in the river system act together to alter the concentration and assemblages of suspended pollen.

Annual discharge of pollen by the Atchafalaya is estimated by extrapolating data for pollen concentrations over the year and using an average discharge value for the whole river. Although the Atchafalaya's annual pollen discharge into the Gulf of Mexico is estimated as less than 10% the amount contributed by the Mississippi, it is an important source of pollen grains to the Gulf of Mexico. It is estimated that both rivers together deliver approximately 3,600 grains cm^{-2} yr^{-1} to the Gulf of Mexico.

RÉSUMÉ

L'objectif de cette recherche est de développer une meilleure compréhension de la nature du transport et de la distribution du pollen dans les bassins fluviaux. L'interprétation des données palynologiques provenant des dépôts sédimentaires demande une compréhension des processus de transport et de dépôt du pollen. Cependant, la recherche sur les processus taphonomiques dans des environnements dynamiquement variables, telles les rivières, est jusqu'ici très limitée et peu concluante. Les deux études dont il est question ici, traitent des questions soulevées par des recherches antérieures, spécifiquement du rapport entre la concentration, la distribution du pollen, et la vitesse du courant, la profondeur de la rivière et l'apport en sédiments.

L'étude résumée dans le chapitre 1, compare les concentrations de pollen et les vitesses à l'intérieur d'une section transversale de la rivière Mississippi à la hauteur de St. Francisville en Louisiane, afin d'examiner les processus de suspension et de transport du pollen. Cinq profils sont étudiés prélevées à six niveaux différents, couplés aux mesures actuelles les vitesses ainsi qu'à des échantillons de surface. Contrairement aux autres études, il ne se trouve aucune correlation signifiante entre les concentrations de pollen et les vitesses.

L'application de la théorie établie du transport des sédiments en suspension au processus de transport des graines de pollen, démontre qu'on ne doit pas compter sur une telle correlation dans une rivière. A cause des vélocités terminales négligeables des grains de pollen, la théorie, pridit une distribution uniforme de la masse de pollen avec la profondeur. Il est aussi démontré qu'une différenciation des dépôts de grains de pollen dans un environnement fluvial est un phénomène peu probable. D'autres mécanismes, tels que la pluie de pollen et la remise en suspension de grains venant du lit de la rivière sont les facteurs les plus probables expliquent la distribution spatiale du pollen dans les rivières.

En vue d'établir les sources potentielles de pollen dans des séquences de sédiments d'origine fluviale, il est important de s'attacher aux facteurs contrôlant annuellement la formation de la charge de pollen dans une rivière, au fil de saisons ce qui est le sujet du chapitre 2. Cette étude examine la distribution saisonnière de la charge de pollen à l'intérieur d'une section transversale de la rivière Atchafalaya, à Morgan City, en

Louisiane. L'étude est basée sur un échantillonage de trois événements, en prenant pour acquis qu'il représentent des périodes d'intensité différente de production de pollen ainsi que des régimes hydrologiques variés. Les données sur les vélocités en cours récoltées concurrremment aux échantillons de pollen, ont permis le développement d'estimations des décharges de pollen, et ce pour chacune des saisons échantillonnées. L'analyse du pollen en suspension dans l'Atchafalaya, suggère qu'il existe deux contrôles principaux de la charge saisonnière de pollen dans la rivière. La production de pollen par la végétation locale et celle du bassin supérieur, ainsi que les processus de mouvement et d'emmagasinage de sédiment dans la rivière, provoquent conjointement le changement de concentration et les assemblages de pollen en suspension.

Le débit annuel de l'Atchafalaya est estimé en extrapolant les données annuelles de concentration de pollen et en utilisant une moyenne de débit pour l'ensemble de la rivière. Bien que la décharge annuelle de pollen de l'Achtafalaya dans le Golfe du Mexique n'est estimé qu'à moins du dizième de celle du Missisipi, il constitue une importante source de graines de pollen pour le Golfe du Mexique. On estime que les deux rivières déversent nviron 3,600 graines cm^{-2} ann^{-1} dans le Golfe du Mexique.

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INTRODUCTION

Quaternary based paleoecological studies help us to perceive global climatic changes and to predict the response of the biotic environment. Due to the ability to remain well preserved in different kinds of sedimentary situations, pollen becomes an important tool in the reconstruction of paleoenvironments. Pollen extracted from offshore marine sediments is known to be generally correlated with onshore and regional vegetation communities (*e.g.* Mudie, 1982). Thus, it becomes possible to use pollen stratigraphies in sediment cores from coastal shelves for the reconstruction of vegetation patterns back to geological time and consequently for our interpretation of paleoclimates. Muller (1959), for example, found marked differences from present-day conditions in older Holocene and Pleistocene samples from the Orinoco Delta of South America. De Vernal and Mudie (1989) concluded that significant changes in the terrestrial environment of Baffin Bay occurred through the Late Pliocene to Holocene.

There are two major pathways by which pollen enters the marine environment, *i.e.* from aerial and fluvial sources. Based upon regional studies, some researchers (Heusser, 1985; Traverse, 1992; Campbell and Chmura, 1994) have concluded that fluvial transport is the major pathway of pollen to offshore areas. Others have found that aerial transport is the critical source in some regions (Hooghiemstra, 1988; Groot and Groot, 1966). Interpretation of palynological data requires an understanding of the sources of deposited pollen grains. Thus, to properly interpret the pollen assemblages from the offshore sediment samples, it is extremely important to understand the relative importance of the pathways of pollen into the marine environment in the region being investigated. Such a study implies detailed knowledge of the pollen input from the onshore and regional vegetation sources as well as of the fluvially transported pollen component for the region.

Pollen transport in fluvial systems has not been sufficiently studied and results of many studies offer contrary findings. Studies of small-scale systems such as small natural streams (Crowder and Cuddy, 1972; Peck, 1973; Brown, 1985) or a laboratory flume (Brush and Brush, 1972) have been performed with adequate sampling resolution to demonstrate details of spatial variability. The very few studies dealing with large fluvial systems (Fedorova, 1952; Chmura and Liu, 1990; Traverse, 1992) have been confined to only one or two depths at single points. Starling and Crowder (1980) and Campbell and Chmura (1994) trying to improve resolution of pollen sampling for large fluvial systems, demonstrated that suspended pollen load was not evenly distributed throughout a vertical of a river cross section which, in turn, raised a question of the factors governing the pattern of distribution of suspended pollen within the body of a river flow.

However, some long-term sampling programs demonstrated a seasonal variability of pollen load in fluvial systems (Starling and Crowder, 1980; Chmura and Liu, 1990; Traverse, 1992). The lack of any spatial resolution of water samples in these studies meant that hypotheses regarding controls and sources of suspended pollen were based on samples from simply one or two points within the river flow.

Rivers have been found to be important sources of pollen to nearshore marine sediments (Muller, 1959; Stanley, 1965; Cross *et al.*, 1966; Mudie, 1982; Heusser, 1985). However, only rough regional estimates of pollen discharge, mostly based upon relationship of pollen concentrations with suspended sediment, have been made (*e.g.*, Groot and Groot, 1966; Chmura and Liu, 1990, Mudie and McCarthy, 1994).

Thus, the nature of the spatial distribution and seasonal variability of suspended pollen in rivers remains unclear. These two studies set out to investigate the relationship between flow dynamics and distribution of suspended pollen (chapter 1) as well as to clarify the sources and controls of the seasonal pollen load in rivers (chapter 2). To address these questions the studies utilize high resolution sampling of the Mississippi and its major distributary the Atchafalaya River. The Mississippi was chosen for the first study because the river is more heavily engineered and presents a typical example of a meandering alluvial channel. The Atchafalaya is a younger fluvial system characterized by a less developed channel and close contact with vegetation of its basin. This river was utilized for the second study on seasonal variability in suspended pollen. The high resolution of sampling makes these studies unique and allows development of a better estimate of pollen discharge by the Atchafalaya River to the Gulf of Mexico.

It is hoped that these two studies together will provide insight into the nature of pollen transport by fluvial systems. The studies are also designed to facilitate understanding of pollen sequences recovered from marine, river, and delta deposits.

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CHAPTER 1

SPATIAL DISTRIBUTION OF SUSPENDED POLLEN IN THE MISSISSIPPI RIVER AS AN EXAMPLE OF POLLEN TRANSPORT IN ALLUVIAL CHANNELS

INTRODUCTION

Pollen is known to enter water bodies by two major pathways, *i.e.*, from aerial and fluvial sources. Fluvially transported pollen is an important source of palynomorphs in alluvial deposits (*e.g.*, Hall, 1985; Fall, 1987), some lakes (*e.g.*, Crowder and Cuddy, 1972; McAndrews and Power, 1973), as well as delta plain deposits (*e.g.*, Muller, 1959; Chmura, 1994). It can also be an important source in near-shore marine sediments (Muller, 1959; Cross *et al.*, 1966; Mudie, 1982; Heusser, 1985; Traverse, 1988 and 1992). For this reason, a number of investigators have been concerned with the nature and processes of pollen transport in various fluvial systems: the Volga River, Russia (Fedorova, 1952), the Delaware River estuary (Groot, 1966), a small Yorkshire stream, England (Peck, 1973), Wilton Creek, Ontario (Crowder and Cuddy, 1972), the Salmon River, Ontario (Starling and Crowder, 1980), Blelham Tarn streams, England (Bonny, 1976), a New Forest stream, England (Brown, 1985), the Mississippi River (Chmura and Liu, 1990) and the Trinity River, Texas (Traverse, 1992).

Based upon pollen distributions in sediments some investigators have assumed that sorting of pollen types occurs during deposition. Catto (1985) suggested that pollen deposition in sediments deposited by a braided stream was driven by the hydrodynamic properties of grains. Fall (1987) studied pollen taphonomy in a canyon stream and found that pollen was differentially deposited in alluvium with higher buoyancy grains incorporated into finer sediments. This, in turn, led Fall to suggest that pollen types were differentially transported and deposited by the stream waters. Her conclusion was that fluvially deposited pollen sequences are unreliable for vegetation reconstruction. However, Hall (1989) re-evaluated Fall's results and explained the stratigraphic differences in pollen assemblages in terms of various upstream sources of pollen and sediment.

Starling and Crowder (1980) reported that pollen concentrations throughout a velocity vertical in Salmon River, Ontario, were correlated with current velocities. Their single set of measurements indicated that suspended pollen was concentrated in the zone of maximum current velocity just below the water surface. In a recent study on the Atchafalaya River (Louisiana), Campbell and Chmura (1994) also found a relationship of pollen load to flow velocity ($r=0.46$, $P<0.01$), but suggested that upstream confluence zones possibly play an important role in distribution of palynomorphs within the body of water flow. Brush and Brush (1972) examined transport of pollen in a sediment-laden flume and observed that concentrations of different taxa were reasonably uniform with depth and with distance along the flume. Finally, Peck (1973), after thorough study of the pollen budget in a small Yorkshire catchment, concluded that pollen, once wetted, acts as any other fine clastic particle, and travels in streams as a part of the wash load. Thus, the variable, and sometimes conflicting results of earlier studies, present questions regarding transportation, dispersion, and sources of pollen grains in fluvial systems. These questions must be addressed to properly understand depositional processes and the nature of pollen assemblages used in reconstruction of paleoenvironments from fluvially related sediments.

The objective of this paper is to clarify the relationships between the velocities of the river flow and pollen concentrations. We attempt to elucidate this problem using point data on current velocities and pollen concentration values from five verticals evenly distributed within a cross section of the Mississippi River at St. Francisville (Louisiana). The relationship of pollen distribution with variations in depth and total suspended sediment concentrations is also examined.

STUDY AREA

The drainage basin area of the Mississippi River at St. Francisville is approximately 2,914,786 km^2. This area includes eight sub-basins: the Missouri, Ohio, Arkansas, upper Mississippi, Illinois, White River, Yazoo, and Lower Mississippi (Figure 1). Thus, the Lower Mississippi at St. Francisville receives water and potentially pollen from the mixed deciduous forest in the northern United States, the prairie region in the west, and deciduous forest in the east.

The Mississippi River has no significant tributaries in Louisiana. The Red River was once a natural tributary, but now its flow is channeled into the Atchafalaya River

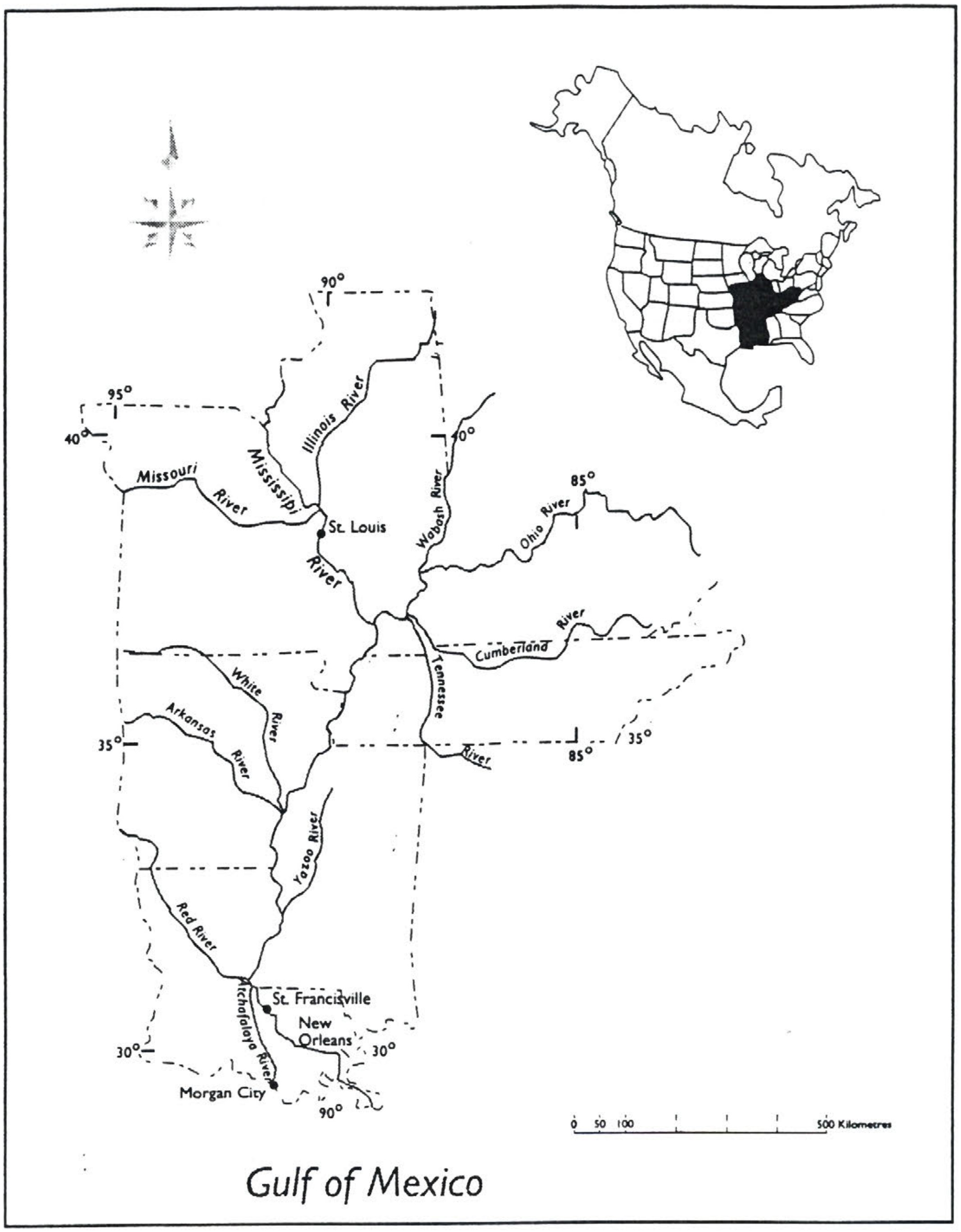

Figure 1. Mississippi River drainage basin. (Modified from Moody and Meade, 1993).

(Figure 1). The nearest major tributary, the Yazoo River, joins the Mississippi approximately 280 km upstream of the sample site. There are a few very minor tributaries along the east bank. The nearest minor tributary, Hardwicks Ditch, is located approximately 10 km upstream and drains the marshy area to the north of the river main stem (Figure 2). Another tributary, Bayou Sara, joins the Mississippi just below the sample site. A major distributary, the Atchafalaya River, is diverted from the Mississippi at the Old River control structure 77 km upstream, where approximately 30% of the Mississippi's flow is directed into the Atchafalaya Basin.

The sample location at St. Francisville, Lower Mississippi River Mile 266.4, was selected because this site is regularly sampled by the U.S. Geological Survey which makes detailed hydrological information available. From the confluence of the Mississippi and Yazoo Rivers to St. Francisville, channel width varies from 0.5 to 1.8 km and is 1 km at the sample site (U.S. Army Corps of Engineers, 1990). At the site, the thalweg is located closer to the south bank, the cross section gradually shallowing towards the north bank (Figure 3). Islands with chutes lying between them and the near shore are characteristic of the Mississippi River in Louisiana. One of these high islands splits the main flow into two parts 8 km upstream of the sample site (Figure 2).

The banks of the reach are bounded by levees. The battures (areas between the levee crest and the water edge) and banks here are mostly composed of mineral sediment, clay, and sand (Moody and Meade, 1993). On the crests of the levees, the soils are sands and silts. Down the levee back slope the soils become finer and the back swamp is composed of fine clays, high in organic material (Kniffen and Hilliard, 1988).

The local vegetation along the reach is likely to contribute to the spectra of the transported pollen load. Two different forest associations have their boundary at the reach studied (Figure 4). To the west of the river, the bottomland hardwoods and cypress association spreads out occupying most of the Mississippi River flood plain. This western region is characterized by a very poor drainage and subdivided into three types: the willow (*Salix*)-dominated sandy batture vegetation, the natural levee and high island vegetation with different kinds of oak (*Quercus*) prevailing, and the bottom or swamp forest composed mostly by tupelo gum (*Nyssa*) and the swamp oaks. The upland hardwoods or

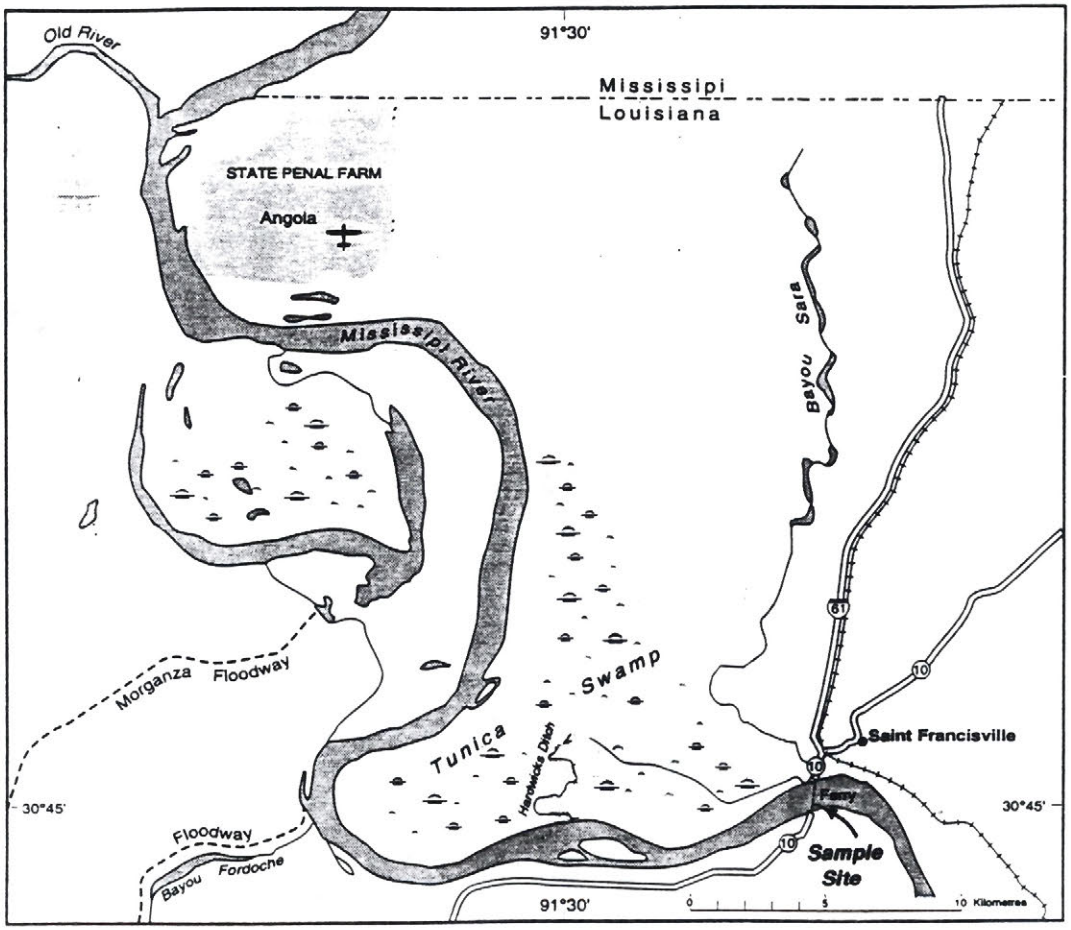

Figure 2. Mississippi River above St. Francisville (modified from U.S. Army Topographic Command, 1954).

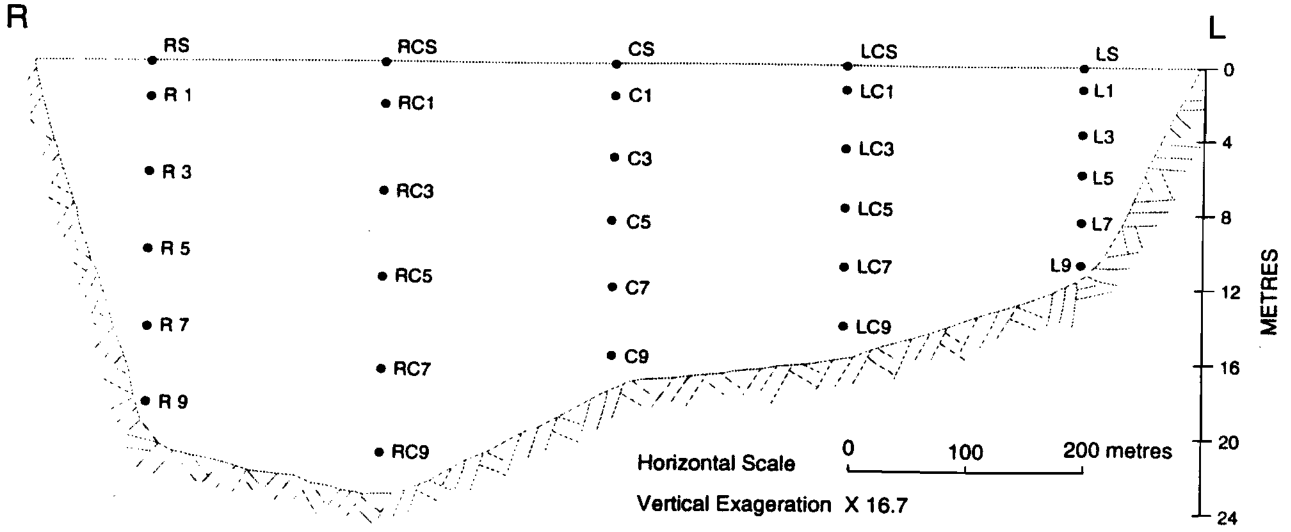

Figure 3. Configuration of cross section from left bank to right bank at St. Francisville, Louisiana. L = left, LC = left-central, C = central, RC = right-central, R = right. Within a vertical profile, samples are numbered from the surface (S) to 0.1 (1), 0.3 (3), 0.5 (5), 0.7 (7), and 0.9 (9) of maximum depth.

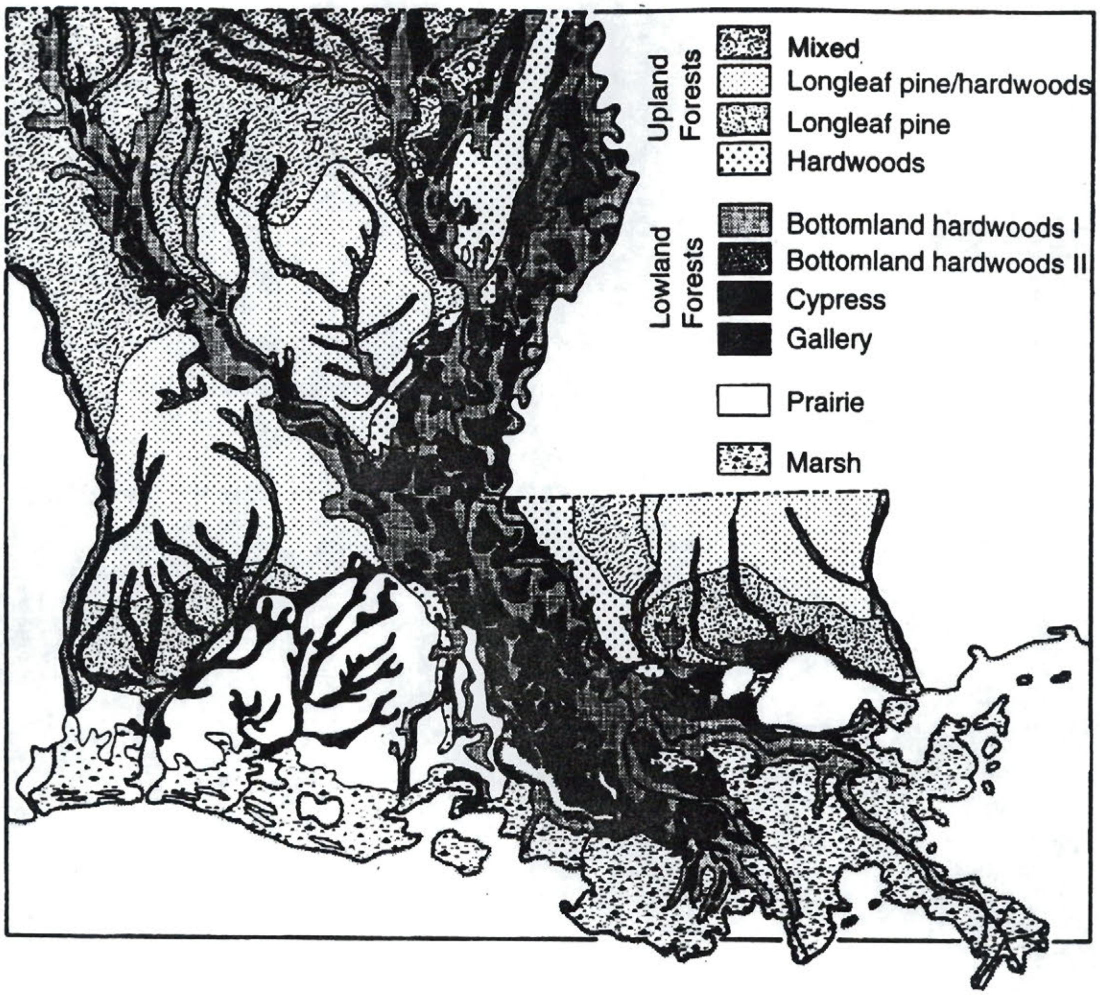

Figure 4. Natural vegetation of Louisiana. (Adapted from Kniffen and Hilliard, 1988).

blufflands forest is located to the east of the river on the bluffs covered with loess deposits. This forest includes live and deciduous oaks and some pine (*Pinus*). Further east are located the mixed and longleaf pine-dominated regions.

METHODS

The river was sampled at St. Francisville on June 17, 1991. At the time of sampling river discharge was 25,500 $m^3 s^{-1}$, normal for the high water stage at this time of year (Moody and Meade, 1993). The water samples were taken with a P63 point sampler on five verticals evenly distributed along the cross section (L = left, LC = left-central, C = central, RC = right-central, R = right) (Figure 3). On each vertical five points were sampled: 0.1, 0.3, 0.5, 0.7 and 0.9 of the full depth as well as the surface waters. Dip, or surface water samples were taken by only partially submerging the mouth of the sample bottle to assure that material floating on the water surface would be collected. Current velocities were measured at each sampling point a few minutes before water sampling.

Water samples ranged in volume from 740 to 980 ml. One tablet of exotic spores of *Lycopodium* (Stockmarr, 1971), containing an average of 12,100 grains each, was mixed into every water sample after which pollen were concentrated by centrifuging. Further treatment was based on the standard procedure described by Faegri and Iversen (1989) including processing with HCl, HF, hot acetolysis, and mounting in glycerin.

Low pollen concentrations necessitated that slides be scanned at 250 x magnification, with identification of individual grains at 630 x magnification. A minimum of 200 pollen grains or 2000 exotic grains per slide were counted. Pollen of the Amaranthaceae family is difficult to distinguish from that of the Chenopodiaceae family. These two types were recognized in the pollen analysis simply as Cheno-Am. All pollen with the characteristic Cupressaceae-type split were counted as Taxodiaceae-Cupressaceae-Taxaceae (TCT). This category has been combined with those grains not split, but recognizable as *Taxodium distichum*, a local and common member of Taxodiaceae (TCT&T). Grains were considered as indeterminable if they were folded, torn, or corroded, so that features, such as pores or colpi, required for reliable identification were lacking. Indeterminable grains were assumed to have mostly derived from resuspension of river deposits and they served as an indicator of fluvial transport (Chmura and Liu, 1990).

RESULTS

The velocity distribution within the Mississippi River cross section at St. Francisville (Figure 5A) is reasonably typical of that found in alluvial channels, with higher velocities near the water surface where the channel is deepest. The lateral depth and velocity asymmetry (with higher values near the right bank) appears to be inherited from the previous bend of the river (Figure 2). Point velocities range from 0.78 m s^{-1} near the bottom on the left (L) vertical to 2.31 m s^{-1} at the surface next to the right bank (Figure 5A). Total pollen concentrations within the cross section vary within almost an order of magnitude (400-2200 grains l^{-1}) and tend to be higher at the surface as well as at the bottom of the shallower part of the cross section, along the left bank (Figure 5B). There is also a noticeably higher pollen concentration at 2 m below the surface near the right bank of the river. The total pollen concentrations are not correlated to current velocities ($r = 0.1$, $P>0.1$). However, total pollen concentrations are significantly correlated with depth ($r=0.50$, $P<0.01$) and tend to be higher closer to the water surface.

Concentrations of suspended sediment within the cross section range from 130 to 330 mg l^{-1} (Figure 5C). The highest concentrations are at 0.5 depth on the left-central (LC) vertical. The lowest sediment concentrations (< 200 mg l^{-1}) correspond to the deepest point samples of four out of five verticals (Figure 5C). The point samples from the surface and 0.1 depth demonstrate similar somewhat lower concentrations. There is a significant Pearson correlation between pollen and suspended sediment concentrations ($R=0.41$, $P<0.05$).

The most abundant pollen types within the cross section are Cheno-Am, Compositae-Tub, *Salix*, TCT, *Quercus*, *Pinus* and Gramineae, which together with indeterminable grains constitute approximately 68% of the total pollen sum. Concentrations of Cheno-Am, Compositae-Tub and *Salix* are highest in surface samples at the central (C) vertical (Figure 6), and the maximum *Pinus* concentration occurs at the surface of the left-central (LC) vertical (Figure 7). The increase in total concentration

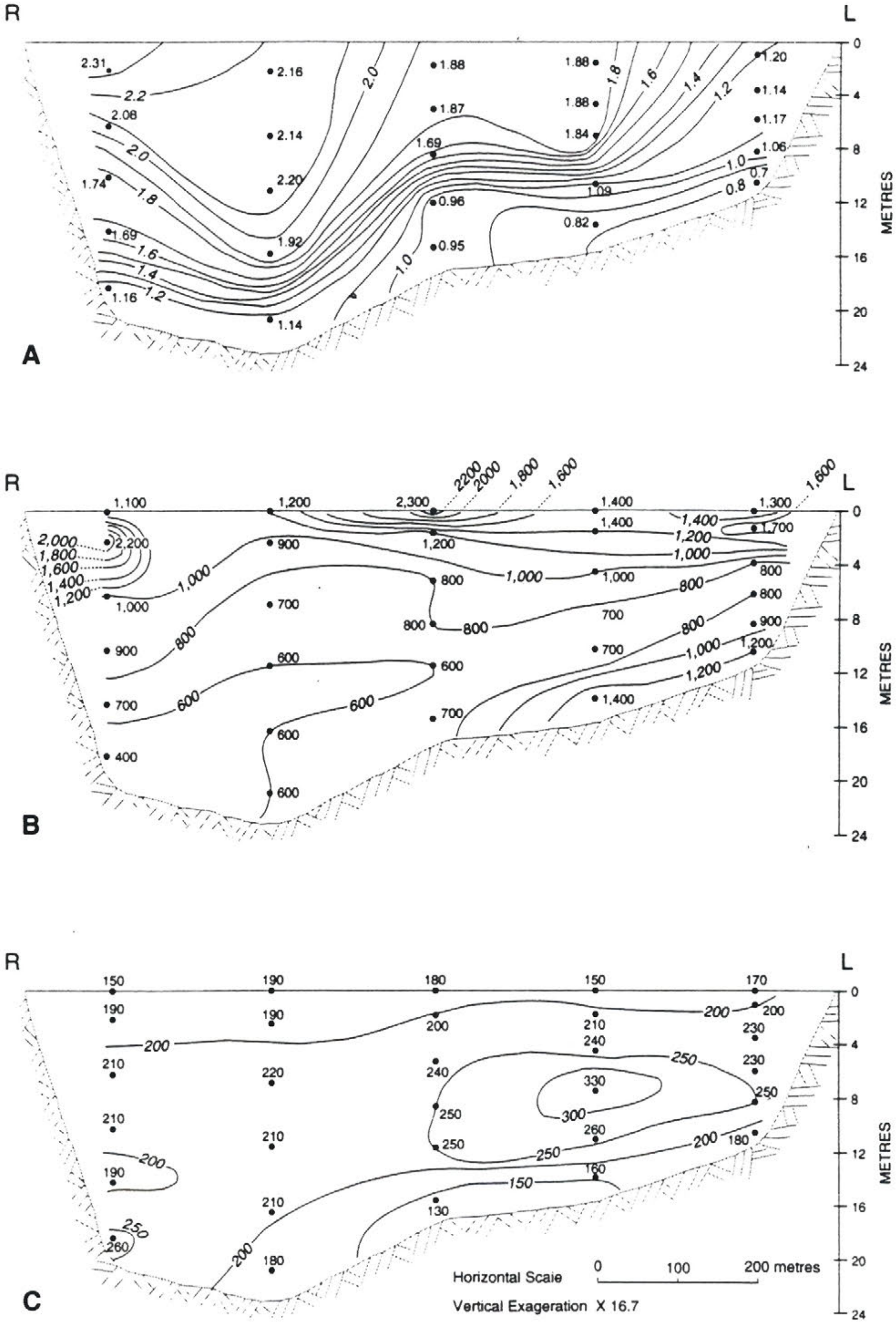

Figure 5. Distribution of (A) current velocity (m sec^{-1}), (B) total pollen and spore concentrations (grains l^{-1}), and (C) sediment concentrations (mg l^{-1}) within a cross section of the Mississippi River at St. Francisville, Louisiana on June 17, 1991; contour intervals = 0.2 m sec^{-1} (A), 200 grains l^{-1} (B), and 50 mg l^{-1} (C).

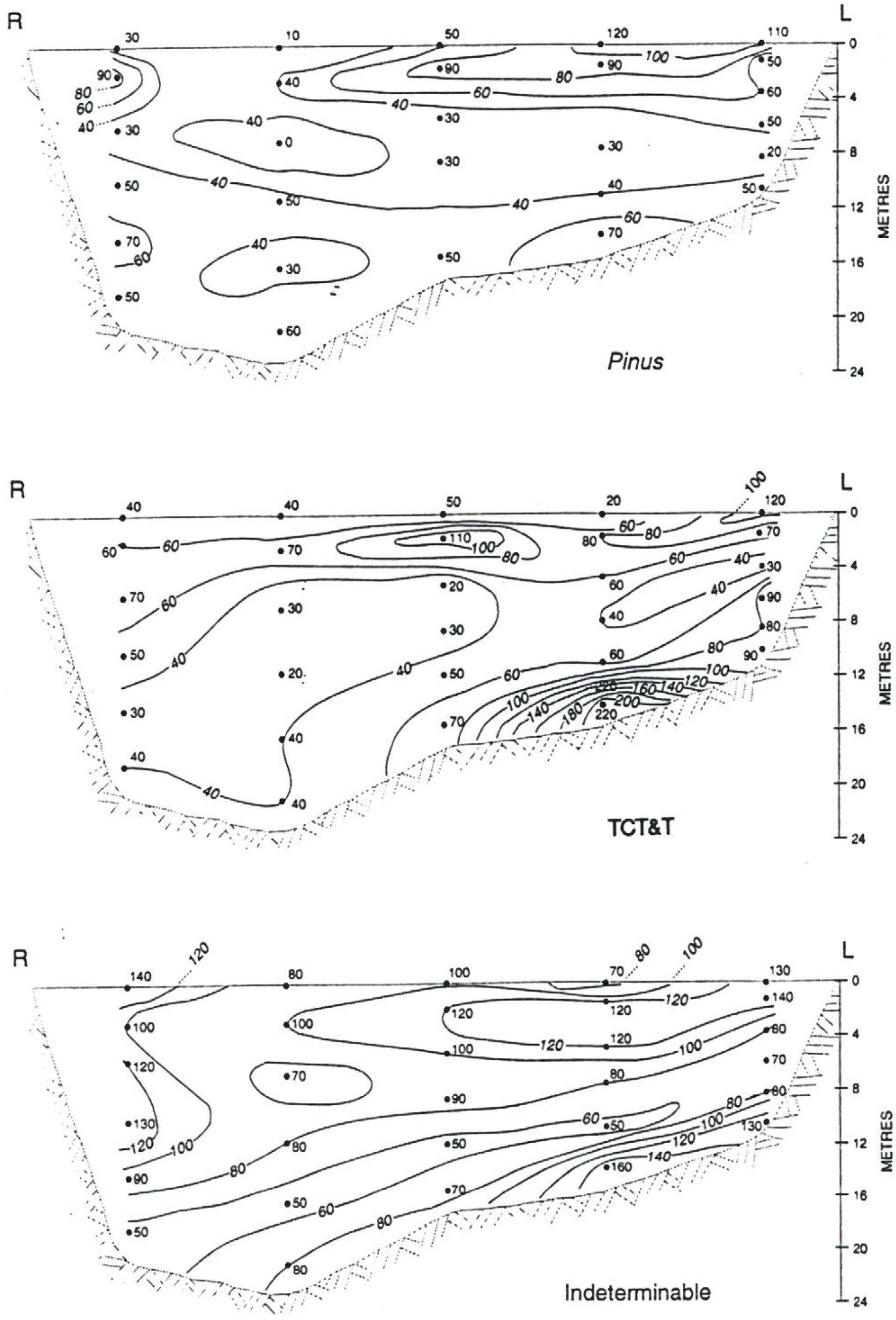

Figure 7. Distribution of *Pinus*, TCT&T, and Indeterminable pollen concentrations (grains l^{-1}) within a cross section of the Mississippi River at St. Francisville, Louisiana, on June 17, 1991; contour intervals = 20 grains l^{-1}.

near the surface next to the right bank (Figure 5) coincides with an increase in *Pinus*, Cheno-Am, Compositae-Tub and *Salix* pollen types (Figures 6 and 7). Maximum concentrations of TCT and indeterminable grains, however, are found at the 0.9 depth (the deepest sample) on the left-central (LC) vertical (Figure 7).

DISCUSSION AND CONCLUSIONS

The pattern of pollen distribution in the St. Francisville cross section can be explained by considering the behavior of the pollen grain as it enters the river realm. Peck (1973) showed that concentration of pollen in streams was correlated with sediment less than 0.1 mm diameter. She and many others (*e.g.*, Muller 1959; Brush and Brush, 1972) have demonstrated that, once wetted, pollen acts as any other fine clastic particle. This implies that the theory of suspended sediment transport applicable to fine sediment can as well be applied to pollen transport. The basic equation describing the particulate concentration profile in a two dimensional open channel flow as given by Rouse (1950) is:

$$\bar{c}/\bar{c}_a=\{(y_0-y)\,a/(y_0-a)y\}^z. \qquad (1)$$

In this equation $\bar{c}$ = the mean concentration of sediment at any elevation y above the bed, $\bar{c}_a$ = the mean concentration of the same size fraction at the arbitrarily chosen elevation a and y_0 = the total depth. Z is the suspended load exponent estimated by:

$$Z=w/\beta k u_* \qquad (2)$$

where w = terminal fall velocity of the sediment, β = the coefficient relating the sediment diffusion coefficient to the momentum diffusion coefficient and usually assumed to be unity, k = the Karman coefficient ($k=0.38$), and u_*= the shear velocity. Shear velocity can be calculated from the equation:

$$u_*=\sqrt{\gamma RS/\rho}=\sqrt{gRS} \qquad (3)$$

in which γ = specific gravity of water, R = hydraulic radius, S = slope and r = fluid density, g = acceleration of gravity.

Although the suspended load equation cannot be applied either at the bed level (where concentration tends to approach infinity) or at the free surface (where it would always predict zero concentration) it can be used to estimate the distribution of mineral sediment or any other small particles within a suspension. The first step in calculation of the suspended load exponent is the estimation of fall velocities for pollen grains. Since the Reynolds number of settling pollen is small (less than 0.5; Brush and Brush, 1972) its terminal fall velocity (W) can be calculated using the Stokes' Law:

$$W=d^2g\,(S.G.-1)/18v \qquad (4)$$

where d = the nominal diameter of grain in cm, g = acceleration due to gravity (981 cm sec^{-2}), v = the kinematic viscosity for water (1.12 x 10^{-2} cm^2 sec^{-1} at 16° C) and $S.G.$ = specific gravity of the particle.

Ragweed (*Ambrosia*) pollen is comparatively well studied and assumed here to represent an average pollen grain. Using data for wet ragweed pollen density reported by Harrington and Metzger (1963) it is possible to estimate the terminal fall velocity for this type of grain from the Stokes' equation *(4)*. As the diameter of ragweed pollen is 2 x 10^{-3} cm (Harrington and Metzger, 1963), its fall velocity in water would be calculated to be approximately 7.9 x 10^{-4} cm sec^{-1}. Thus, the suspended pollen load exponent ($Z=w/ku_*$) for the Mississippi River at St. Francisville, (u_*=1.43) is 1.5 x 10^{-3}. With the suspended load exponent being so negligible, the ratio $\bar{c}/\bar{c}_a$ in equation *(1)* tends to unity. For example, the ratio of ragweed pollen concentrations at 0.1 to 0.9 depth would be approximately 0.994 as calculated from equation *(1)*. Consequently, steady state concentrations on one vertical will be practically uniform. The variations in terminal fall velocities for different pollen types (Brush and Brush, 1972) and the alterations in size and shape which can take place due to soaking (Davis, 1967) are too negligible, in terms of equation *(1),* to noticeably influence the vertical distribution of suspended pollen load. Note, however, that non-uniform vertical pollen profiles can conceivably occur if vertical mixing has not had time to be effective, due to insufficient travel distance, from a point of aerial deposition on the surface or local bottom resuspension.

Brush and Brush (1972) studied pollen transport in a sediment-laden flume and found that experimental data agreed with those predicted by equation *(1)*. The vertical concentration profiles of the 13 different taxa used in their experiment were nearly uniform with depth, in spite of slight differences in hydrodynamic properties of different pollen taxa. However, observations on natural rivers have demonstrated some differences in pollen concentrations along a single vertical. In the Salmon River, Ontario, Starling and

Crowder (1980) found that pollen was concentrated at the surface with a second noticeable peak closer to the bed. In the Atchafalaya River in June, 1991, the distribution of pollen load varied from 1586 to 5213 grains l^{-1} on the easternmost vertical with significant variations on the other verticals (Campbell and Chmura, 1994). The cross section at St. Francisville reported here demonstrates a high degree of vertical variability of total pollen concentrations (*e.g.*, 600-2,300 grains l^{-1} on the central vertical) (Figure 5B). Since the theory of equilibrium suspended sediment transport does not explain these departures from uniform distribution, they must be attributed to other factors.

The occurrence of higher pollen concentrations at the surface of the Salmon River in June found by Starling and Crowder (1980) could be due to a heavy pollen rain over the area. The timing coincided with abundance of aerial pollen in the air produced by flowering trees (*e.g.*, *Pinus*). The ability of pollen grains to penetrate the air-water interface is affected by surface tension. It has been found that in a flume a pollen grain becomes submerged within a few meters down flow of deposition on water surfaces due to the turbulent nature of fluid (Brush and Brush, 1972). However, in natural rivers, under conditions of continuous pollen rain, surface concentration maxima are likely to exist. In addition, bisaccate grains (*e.g.*, *Pinus* and *Picea*), when dry, remain afloat for much longer periods due to buoyancy provided by air bladders (Fedorova, 1952; Brush and Brush, 1972). At the Salmon River site the pollen influx through the air-water interface would have brought about higher concentrations at the surface due to a simple delay in mixing. As current velocities tend to be greater closer to the surface due to hydrodynamic properties of the flow, the correlation between current velocity and pollen concentration values may simply be coincidental. This was probably the case in the study on the Salmon River (Starling and Crowder, 1980). The heavy pollen rain at the time of sample collection mentioned by authors warrants this conclusion.

Other mechanisms could be at work in the Atchafalaya River where the overall pattern of pollen concentrations was probably affected by resuspension of palynomorphs from the bed (Chapter 2) and possibly by the confluence zone located just upstream of the sample site (Campbell and Chmura, 1994). Since turbulent motion occurs throughout a cross section of a natural stream some pollen grains may reach the bed. Once a grain hits the bed it may adhere to larger particles of sediment and become intermixed with the moving sediment grains (Brush and Brush, 1972). Once deposited, the grain can stay at rest for some time before becoming washed out and involved into further downstream transport. Under conditions of high turbulence present at the bottom during high water stages, previously deposited grains are especially likely to become again a part of the suspended load.

Two distinctive patterns are evident in the distribution of the most important pollen taxa within the cross section at St. Francisville. High concentrations of total pollen at the surface coincide with maxima of *Pinus*, Cheno-Am, Compositae-Tub, and *Salix* pollen (Figures 6 and 7). This pattern might be attributed to the pollen sources from local vegetation on upstream islands and river banks where the common vegetation is willow (*Salix*) and herbaceous plants which are members of the Compositae, Chenopodiaceae, and Amaranthaceae families. As *Pinus* is noted for its aerial transport it is not unexpected to find aerial deposition at this time of year. The second pattern, high concentrations of TCT&T and indeterminable pollen close to the bottom on the left (L) and left-central (LC) verticals (Figure 7) could be attributed to resuspension of pollen previously incorporated into the bed. This hypothesis is supported by the significant correlation between pollen and suspended sediment concentrations. Local *Taxodium* blooms in February and some of its grains might have been incorporated into the bed by the time of sampling. Then this rise in bottom concentrations may be attributed to resuspension of *Taxodium* as well as other badly preserved (indeterminable) grains from the bottom in this part of the cross section.

The secondary rise in the indeterminable pollen concentrations, in the subsurface layer (Figure 7), could be due to both the influx of deteriorated grains washed from soils in the upper basin and those resuspended from upstream banks and point bars exposed during low-water stages. As both sediment sources are highly aerobic, pollen contained within them tends to be degraded (Traverse, 1988). During rising river stages badly preserved grains would be resuspended from river banks and bars and become an additional source of the indeterminable pollen load.

Higher total pollen concentrations located close to the surface (Figure 5B) are probably brought about by aerial pollen deposition at St. Francisville. The single-point variations in the concentration profiles (Figures 6 and 7) could be an artifact of a single sampling and caused by the turbulent eddies that are typical of any turbulent flow and can influence instantaneous concentrations of the suspended pollen load.

The differential deposition of pollen grains found by Fall (1987) and Catto (1985) is unlikely to occur in the fluvial environment. Fall (1987) assumed that Cheno-Am, *Artemisia*, and other Tubuliflorae grains are expected to be deposited from more turbulent flow than, for example, *Pinus, Quercus,* or *Populus* pollen. This assumption, however, cannot be supported in terms of the theory of suspended sediment load transport. For instance, wet *Pinus* pollen, which according to Fall (1987) should be deposited only in areas with slack water, has one of the highest fall velocities (3.2×10^{-1} cm sec^{-1}). This is two orders of magnitude higher than that for the *Ambrosia* grain shown to remain constantly in suspension. Therefore, if differential deposition did occur, *Pinus* would be expected to settle out before many other grains mentioned by Fall. The *Picea* pollen grain, which was assumed by Catto (1985) to differentially deposit from still water, has an even greater fall velocity of 5.2×10^{-2} cm sec^{-1} (Brush and Brush, 1972), and thus would not be expected to be concentrated by low flow conditions.

Reasons for such differences in pollen spectra of fluvial deposits should be looked for in different sediment and pollen sources as was suggested by Hall (1989). Consequently, fluvially deposited palynomorphs can be of use for environmental reconstructions provided that the sources of the pollen grains and sediment in the river are established.

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CHAPTER 2

SEASONAL VARIATIONS IN SUSPENDED POLLEN LOAD IN THE ATCHAFALAYA RIVER, U.S.A.

INTRODUCTION

Although it has been shown that fluvially transported pollen is an important part of pollen assemblages recovered from different kinds of depositional environments (*e.g.*, McAndrews and Power, 1973; Muller, 1959; Mudie, 1982), a very limited number of studies has dealt with direct measurements of pollen loads in rivers and streams. One of the first studies of the transport of pollen and spores by flowing waters was conducted by Fedorova (1952). Four water samples from the middle and lower Volga River and its major distributary, the Achtuba, were taken within a six week time span. Analysis of the samples revealed that pollen concentrations ranged from 230 to 460 grains l^{-1} of water. Later investigations have demonstrated that concentrations of pollen within rivers and streams can vary from 11 grains l^{-1} in the Salmon River (Starling and Crowder, 1980) to 230,000 grains l^{-1} in the New Forest stream sampled by Brown (1985).

Fedorova (1952) also suggested that the amount of pollen carried by a river might vary noticeably throughout the year. Peck (1973) studied pollen in a small Yorkshire stream throughout a year and found significant seasonal variability in total pollen concentrations. Long-term observations on Wilton Creek, Ontario (Crowder and Cuddy, 1972), Blelham Tarn streams, England (Bonny, 1976), the Salmon River, Ontario (Starling and Crowder, 1980), Trinity River, Texas (Traverse, 1992), and the Mississippi (Chmura and Liu, 1990) have shown the existence of prominent seasonal variations in total concentrations of palynomorphs. Various hypotheses have been advanced to explain this seasonal variability. Bonny (1976) found that peaks of pollen load in the Blelham Tarn stream generally coincided with blooming periods. Crowder and Cuddy (1972) found the highest concentrations of pollen and spores in Wilton Creek, Ontario were in July when the flow was minimal. They suggested that in summer the source of most pollen is from direct deposition on the water surface.

In contrast, Peck (1973) found peaks of pollen concentration in a small Yorkshire stream outside the pollen production season, *i.e.*, in November, January and March.

These maxima of pollen concentration coincided with high values of water discharge and suspended sediment transported by the stream. Studies conducted by Starling and Crowder (1980), Brown (1985), and Chmura and Liu (1990) also demonstrated that pollen concentration can be positively related to hydrologic discharge and suspended sediment concentrations.

Thus, different factors may influence the concentration of total pollen in various streams and rivers. Peck (1973) identified three major variables that determined pollen supply to the stream: stream discharge, amount of rainfall, and pollen production. Using multiple regression, she further showed that individual pollen taxa were differentially correlated with these three variables. Tree species proved to be better correlated with pollen production, while pollen of herbaceous taxa showed better response to variations in discharge and amount of rainfall.

One could expect some variations not only in total pollen load carried by a river, but also in the spectra of pollen assemblages recovered from water samples taken at different seasons. A number of studies have demonstrated that such fluctuations of pollen spectra do occur in fluvial systems. In his work on the Trinity River in Texas, Traverse (1992) found that different pollen taxa constituted various percentages of the pollen sum in different months of the year. For example, aboreal pollen taxa such as *Quercus, Pinus,* and *Taxodium* were important in pollen assemblages of the Lower Trinity River at the end of the winter and in the spring months, yet pollen of Gramineae, Compositae, and Chenopodiaceae families become predominant in the fall-winter assemblages. The same tendency had been shown by Chmura and Liu (1990) for the Mississippi River.

The geographic position and size of a fluvial system also affects the total concentration and spectra of pollen load carried by its waters. Fedorova (1952) concluded that rivers that cross different vegetation zones can carry a pollen signal characteristic of a particular vegetation zone far beyond the boundaries of distribution of its taxa. She found that in the Volga River, pollen of *Picea* and *Sphagnum* spores were transported over great distances (1400 and 1300 km, respectively) downstream. Even when mixed with pollen of local taxa, the transported *Picea* and *Sphagnum* constituted a high percentage of the total pollen sum in downstream samples. Groot (1966) also found that the pollen spectra of the

Delaware River estuary represented both local and regional vegetation. Similar conclusions about long distance transport of pollen grains have been made by Traverse (1992) for Trinity River and Chmura and Liu (1990) for the Mississippi.

Brush and DeFries (1981) concluded that long distance transport was not a critical source of pollen grains in their study on the Potomac estuary and discovered a strong correlation between pollen load and adjacent vegetation. Studying alluvial sediments from an arid region, Solomon *et al.* (1982) found that pollen in alluvium was derived entirely from the floodplain. Thus, the relative importance of the different factors may vary for different rivers and it is extremely important to fully understand the mechanism of pollen load formation in a particular fluvial system before one begins any interpretation of pollen assemblages. Direct analyses of the pollen load carried by rivers are expected to be a useful tool in elucidating these problems.

In this chapter I examine seasonal changes in concentrations and spectra of suspended pollen within a cross section of the Atchafalaya River and consider the factors which could serve as important controls on the pollen load in this river. The sampling scheme was designed to coincide with periods of peak pollen production within the Mississippi drainage basin (June) and minimum pollen production (March). A third sample event enables comparison of low (October) and high (June, March) discharge conditions. This study is unique in that it employs an array of point samples of water and velocity taken at regular depths throughout a river cross section.

The pollen load transported by rivers, if not deposited within the fluvial system itself, eventually becomes a component of sediments of the receiving basin. In some regions the fluvially transported pollen is expected to become an important part of the offshore pollen assemblage (Heusser, 1985, 1988; Mudie, 1982; Cross *et al.*, 1966; Stanley, 1965; Muller, 1959; Traverse, 1988). To appropriately interpret pollen assemblages from marine sediments, it is important to know the contribution by rivers.

Most estimates of pollen discharge to the ocean have been based on sediment discharge calculations. Groot and Groot (1966) estimated the amount of pollen delivered to the ocean by major streams on the east coast of North America ($1.5\text{x}10^{17}$ grains yr^{-1}), by assuming that the sediment transported to the ocean contained on average 20,000 grains g^{-1}. Chmura and Liu (1990) calculated the number of pollen grains discharged annually into the Gulf of Mexico by the main trunk of the Mississippi River as approximately 10^{19}. Campbell and Chmura (1994) estimated the pollen discharge of the eastern Atchafalaya outlet as roughly similar to that of the Mississippi and suggested that both the rivers contribute about 2×10^{19} grains of pollen per year to the Gulf of Mexico.

I am not aware of any attempts which have incorporated pollen concentrations from throughout a river cross section with multi-sectional hydrologic discharge calculations for different seasons to estimate annual pollen discharge. In this chapter I present refined estimates of the yearly pollen contribution of the Atchafalaya as well as a refined estimate for annual pollen discharge by the Mississippi to the Gulf of Mexico.

STUDY AREA

The sample site is located on the Atchafalaya River at Morgan City, Louisiana (Figure 1). The Atchafalaya is a major distributary of the Mississippi River, which discharges its waters into the Gulf of Mexico through two outlets, the Lower Atchafalaya River and the Wax Lake Outlet (Figure 2). The cross section sampled is located at Berwick Bay, where the Atchafalaya receives water from Flat Lake, the Intracoastal Waterway through Drews Pass, and the lakes and channels of the Lower Atchafalaya Basin via Stouts Pass. Bayou Teche joins the flow at Berwick navigation lock immediately south of this confluence (Figure 3). The bottom profile of the Atchafalaya River at Berwick Bay gradually shallows towards the left bank and the thalweg is located close to the center of the river (Figure 4). Additional description of the sample site at Morgan City is found in Campbell and Chmura (1994).

The landscape is urban in nature and banks at the sample site and immediately upstream are stabilized. Two spans of Louisiana Route 90 (each supported by four pillars) cross Berwick Bay at Morgan City. The northern span was used as a mooring base for downstream sampling (Figure 3).

As the Atchafalaya receives approximately 30% of the Mississippi's flow as well as all the flow of the Red River, its pollen assemblage could reflect the diverse vegetation

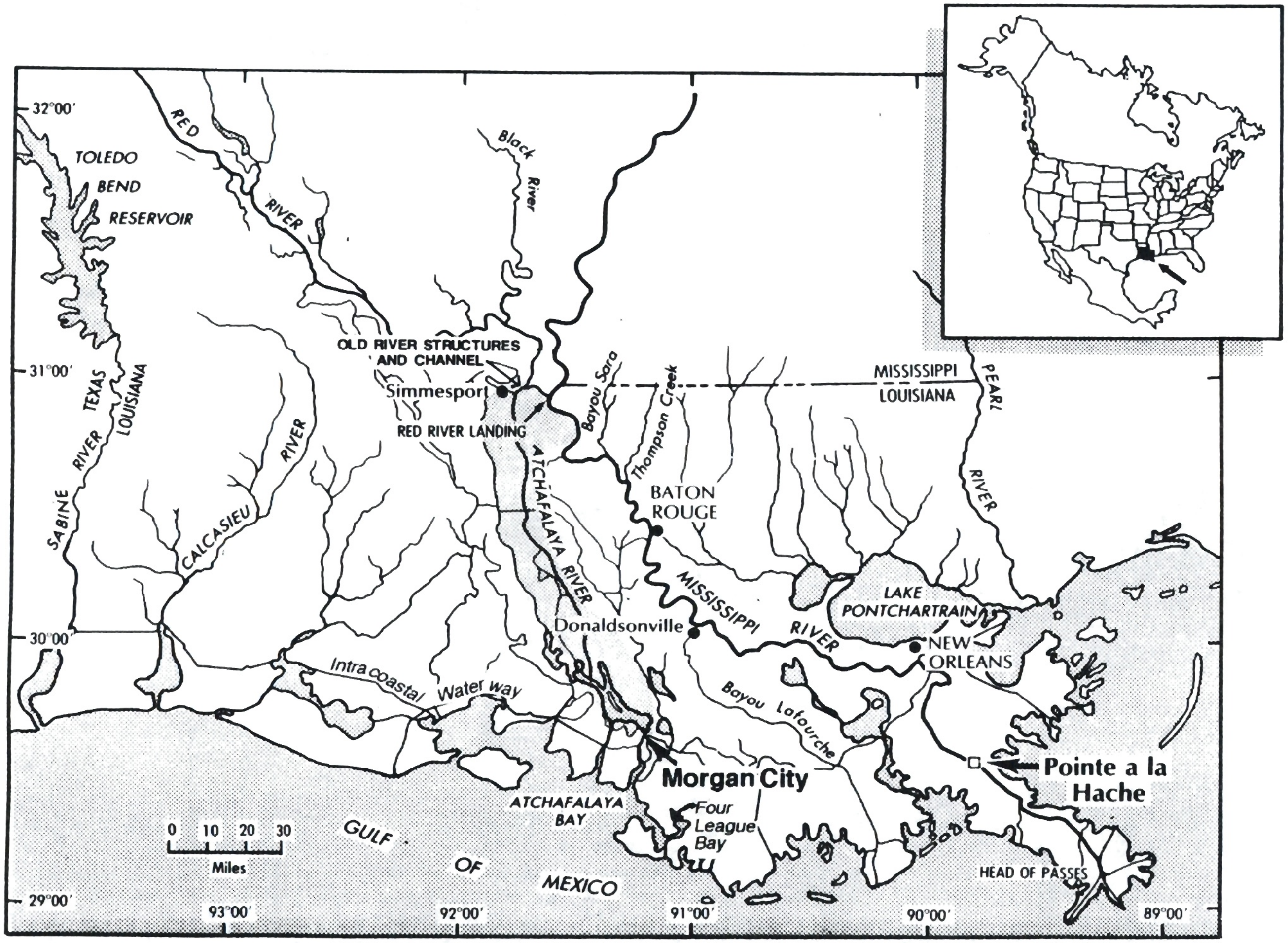

Figure 1. Drainages of Lower Mississippi and Atchafalaya River. Shaded area represents the Atchafalaya basin including the Morganza and West Atchafalaya floodways.

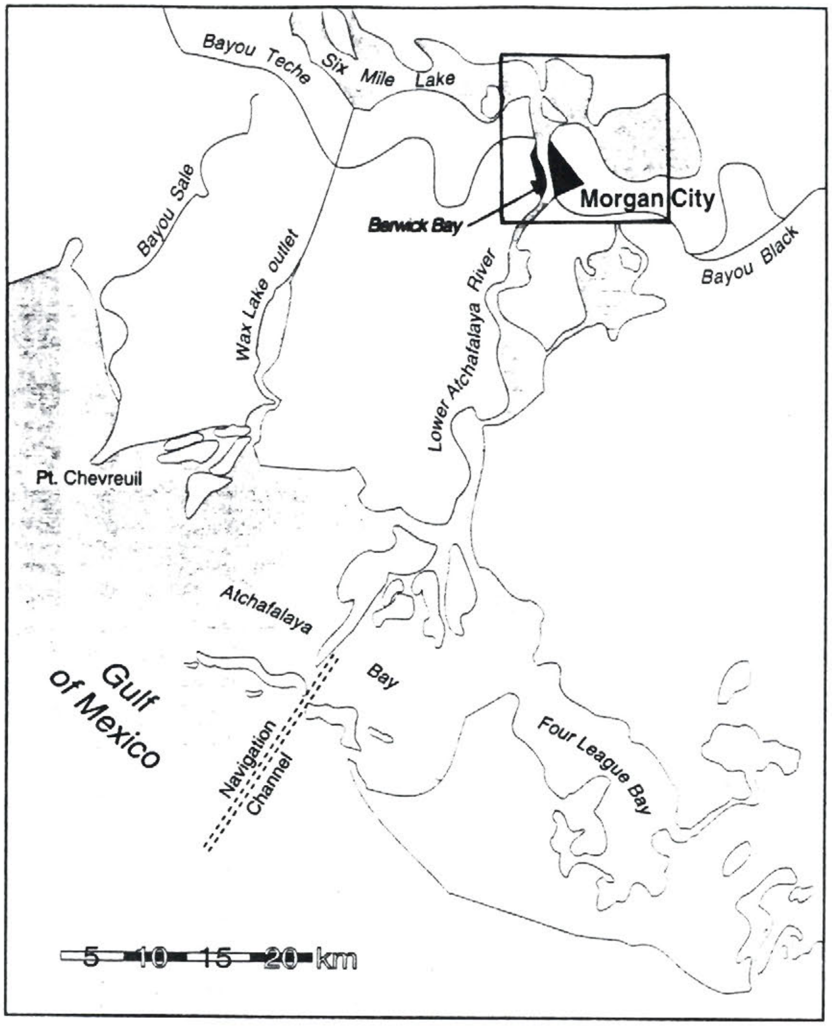

Figure 2. Lower Atchafalaya River Basin and Atchafalaya Bay. Inset area (Berwick Bay) is enlarged in Figure 3.

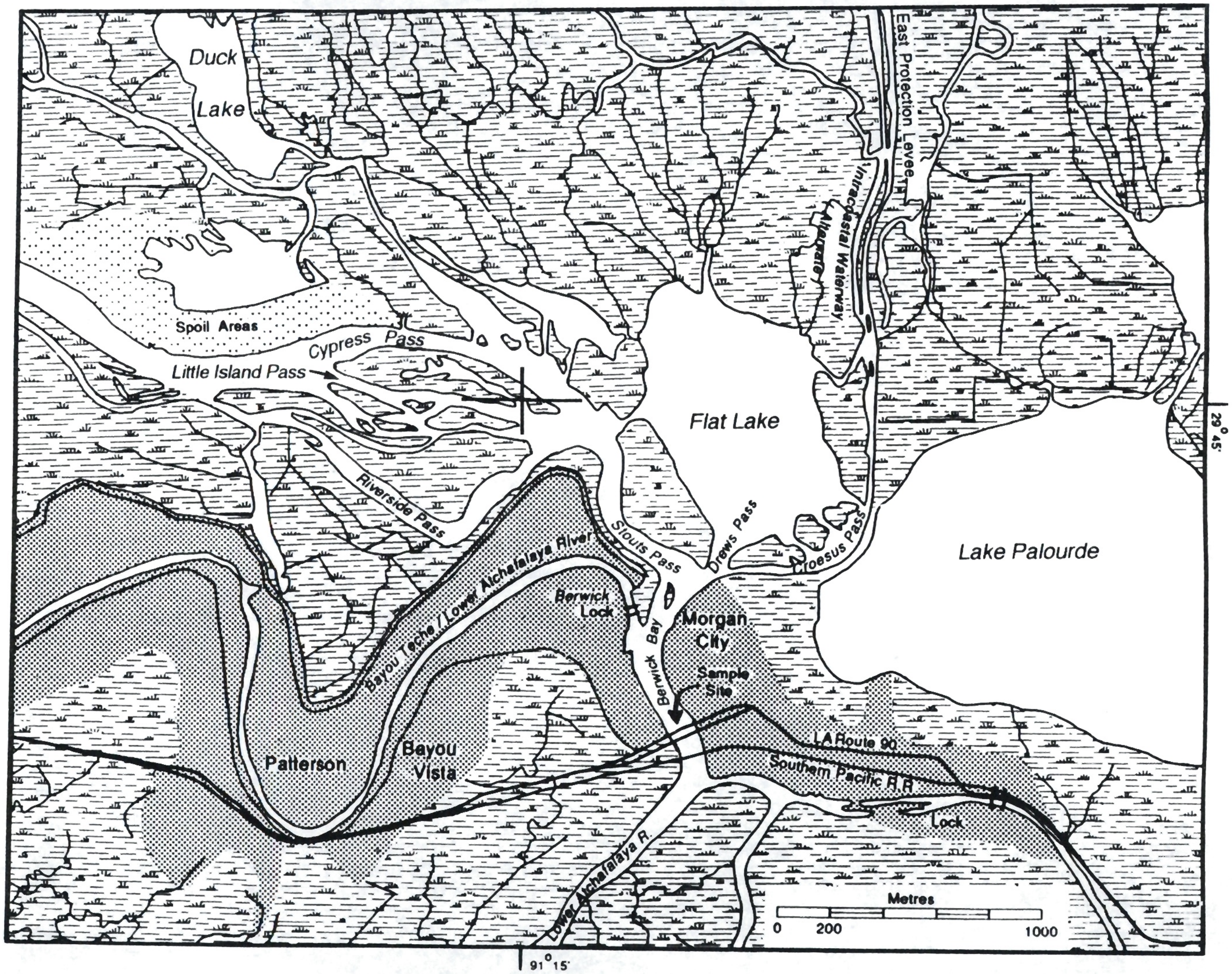

Figure 3. Location of cross section at Berwick Bay, Morgan City, Louisiana.

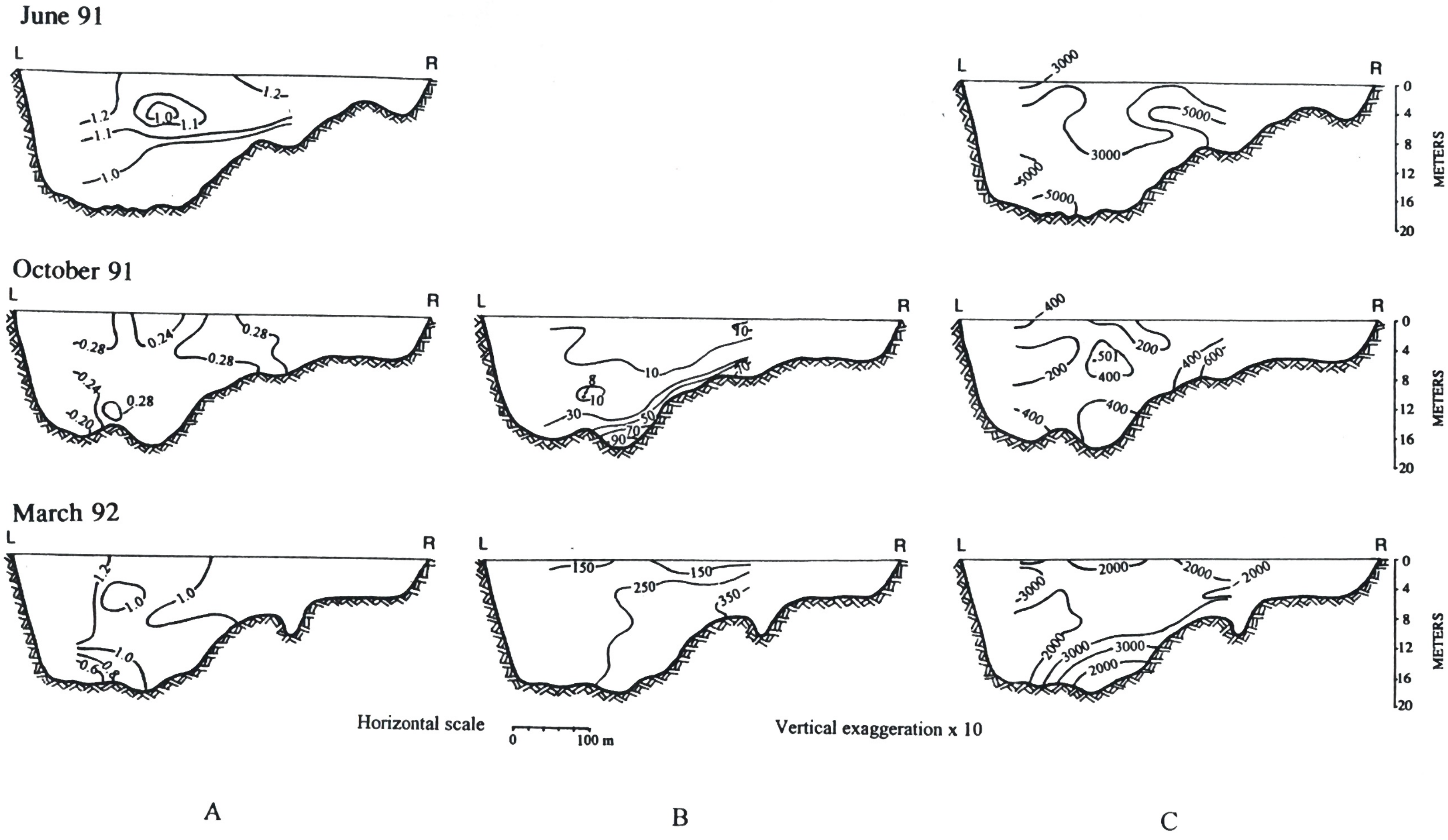

Figure 4. Distribution of A) current velocity (m sec^{-1}), B) sediment concentrations (mg l^{-1}), and C) total pollen and spore concentrations (grains l^{-1}) within cross section of the Atchafalaya River at Morgan City, Louisiana at different seasons (view upstream). Suspended sediment data are not available for June.

zones drained by both the rivers. It is expected that the Atchafalaya will also receive pollen characteristic of the local vegetation of the Atchafalaya Basin. Immediately upstream in the Atchafalaya Basin, marsh and swamp vegetation predominates. The dominant tree species in the swamp forest include cypress (*Taxodium distichum*), willows (*Salix* spp.), tupelo gum (*Nyssa aquatica*), drummond red maple (*Acer drummondii*), and ashes (*Fraxinus* spp.). The herbaceous marsh is mostly characterized by such species as roseau cane (*Phragmites australis*), cattail (*Typha* spp.), saw grass (*Cladium jamaicense*), three-corner grass (*Scirpus olneyi*), and pickerel weed (*Pontederia cordata*), as well as some aquatic plants such as alligator weed (*Alternanthera philoxeroides*), and water hyacinth (*Eichhornia crassipes*). In the upper Atchafalaya Basin, landscapes are covered by bottomland hardwoods, including oak (*Quercus*), hickory (*Carya*), maple (*Acer*), elm (*Ulmus*), and some pine (*Pinus*). The Red River drains areas of longleaf pine forest (Kniffen and Hilliard, 1988). Most of the tree species in the area bloom early in spring (February-April). Some are characterized by extended blooming periods, *e.g.*, *Salix nigra* (February-June), or by a successive bloom of different species of the same genus, *e.g.*, *Quercus* spp. (Burns and Honkala, 1990). Herbaceous plants of upstream vegetation start flowering later, in summer.

METHODS

The river was sampled three times, on June 12, 1991, October 23, 1991 and March 11, 1992. The sampling technique used in the study was similar to that described by Campbell and Chmura (1994) and in Chapter 1. Water samples were taken with a P63 point sampler at the surface and 0.1, 0.3, 0.5, 0.7 and 0.9 depth on five verticals spaced across the river cross section (Figure 4). Each point sample was paired with a current velocity measurement with the exception of surface samples.

Depths measured on the same days by the U.S. Geological Survey Water Resource Division (Baton Rouge, Louisiana) were used to describe the bottom profile. Hydrologic discharge calculations were made by dividing the cross section into five panels, each panel containing a vertical on which mean weighed current velocities were estimated. The area for each panel was calculated with respect to the observed changes in the bottom profile.

The volume of water samples for pollen analysis varied from 0.51 to 0.98 l. A tablet of marker grains (*Lycopodium*) was added to each sample to enable calculation of pollen concentrations (Stockmarr, 1971). For samples collected in October and March, suspended sediments were concentrated by centrifugation, dried, and weighed. Sediment concentrations are not available for the June samples. Total sediment concentrations were calculated by subtracting the assumed pollen weights from total sediment weights using an assumed average mass of pollen grain of 4.8×10^{-6} mg (Brush and Brush, 1972).

Pollen was concentrated using techniques described by Faegri and Iversen (1989). Spores and pollen grains were counted at 400x magnification until 200 pollen grains and/or 2000 marker grains had been found. Grains were considered as indeterminate if they were deteriorated beyond the identification criteria. All pollen grains with a characteristic split were identified as Taxodiaceae-Cupressaceae-Taxaceae (TCT) type. Those with visible exit papillae (Kapp, 1969) were counted as *Taxodium*. Both the types were joined in further analysis under a category referred to as TCT&T. The 0.1 depth sample from the left vertical for October (Figure 4b) was not used in the analysis because of an exceptionally high concentration of Compositae pollen (600 grains l^{-1}) assumed to be the result of contamination during sampling or processing.

RESULTS

The velocity profiles are characterized by a complicated point velocity structure, with some high and low velocity cells located within the body of the flow (Figure 4a). Average velocities within the cross section are nearly four times higher in June and March than in October (Figure 5). The 20-year average estimate of water discharge at Simmesport, Louisiana equals 5,100 $m^3 s^{-1}$ (Bahr *et al.*, 1983). This flow is assumed to be equally split between the Wax Lake and the Lower Atchafalaya River outlets (U.S. Army District, New Orleans, 1984). Assuming that roughly one half of the flow passes through the channel at Morgan City, discharges in March and June of 1991 were above average and in October below the long term average. The vertical distributions of classed depths demonstrate a decrease in velocity towards the bed for June and March, while under the low flow conditions of October, velocity values are evenly distributed from the surface to

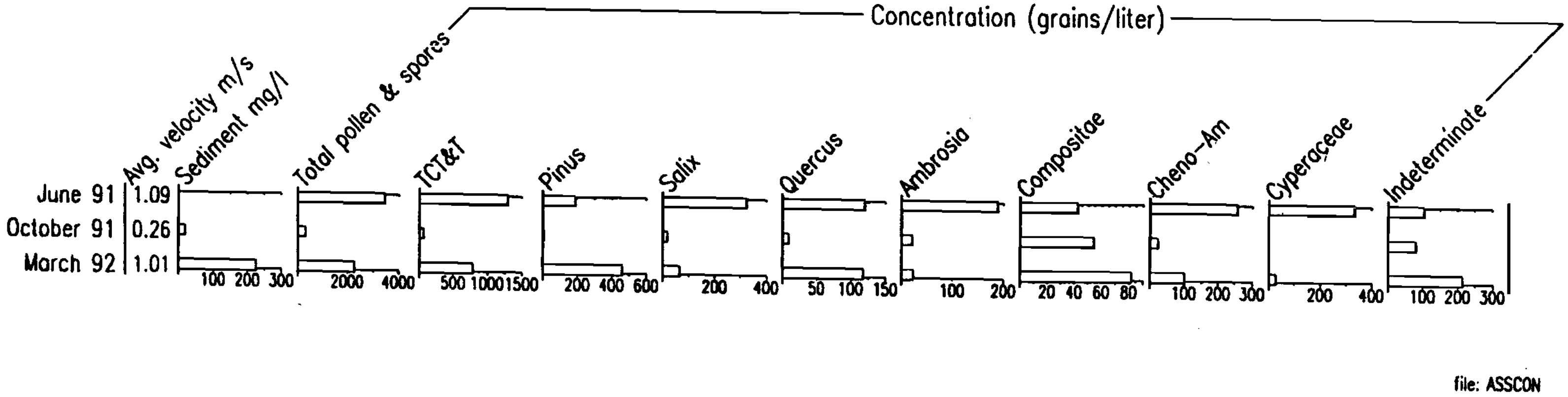

Figure 5. Average pollen concentrations (grains l^{-1}) with corresponding average values of current velocities (m s^{-1}) and sediment concentrations (mg l^{-1}) within cross section of the Atchafalaya River at Morgan City, Louisiana, at different seasons.

the bottom of the cross section (Figure 6).

Seasonal distribution of suspended sediment within the cross section demonstrates a pattern similar to that of velocity, with the October level lower than that measured in March (Figure 4b). Sediment concentrations are highest at the bottom of the flow and lowest at the surface (Figure 6). Sediment concentrations are somewhat higher towards the left bank (Figure 4b). The shape of bottom profile also undergoes conspicuous seasonal changes (Figure 4). Scour and deposition take place at different sections of the bed at different seasons.

The average total pollen concentration over the three sample periods is approximately 2000 grains l^{-1}. Average monthly concentrations demonstrate a seasonality in distribution (Figure 5), with the lowest concentration in October and highest in June. The vertical distributions of total suspended pollen show a consistent increase towards the bed at all seasons, with the difference most prominent in June (Figure 7). At all three sample times, the highest pollen concentrations can be observed close to the bottom at the deepest part of the cross section and towards the left bank (Figure 4c). Thus, seasonal and spatial distribution of total pollen load within the cross section is very similar to that of suspended sediment load. This visual similarity is expressed by a high Pearson correlation between sediment and pollen concentrations ($r=0.85$, $P<0.001$).

Pollen assemblages show seasonal changes. Pollen of aboreal taxa (tree and shrub species) are most abundant within the cross section in June and March, whereas in October their percentage of the total pollen sum is equal to that of upland herbs (Figure 7). Upland herbs are the second most abundant pollen type in June and March. Pollen of aquatic plants peaks in June, at 10% of the pollen sum. The most abundant aboreal types within the cross section are TCT&T, *Pinus*, *Salix*, and *Quercus*, while herbaceous vegetation is mainly represented by *Ambrosia*, Compositae, Chenopodiaceae-Amaranthaceae (Cheno-Am) and Cyperaceae. The grains attributed solely to *Taxodium distichum*, constituted less than 2% of total sum in June and October, but reached 8% in March. Indeterminate grains are also important in pollen assemblages recovered from the river samples. Each of the above pollen types constitutes >5% of the total pollen sum in one or more cross section and together comprise greater than 80% of the total pollen sum

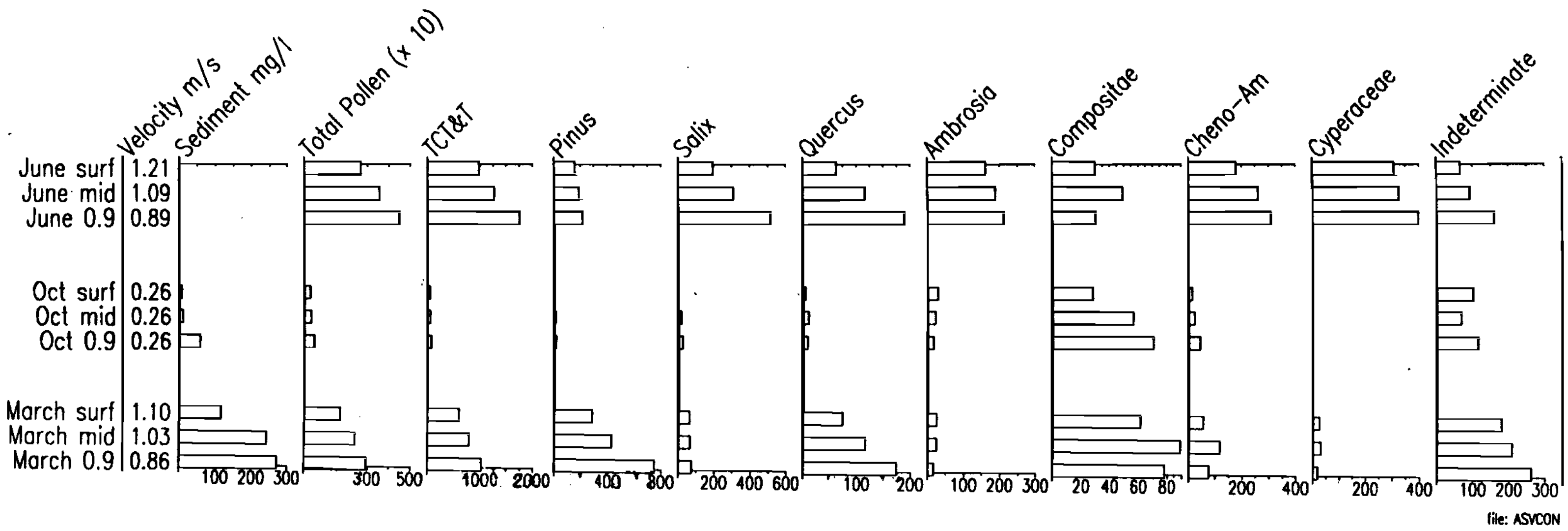

Figure 6. Vertical distribution of pollen concentrations (grains l^{-1}), current velocities (m s^{-1}), and sediment concentrations (mg l^{-1}) within cross section of the Atchafalaya River at Morgan City, Louisiana, at different seasons. Surf = averaged surface samples; mid = averaged 0.1-0.7 depth samples; 0.9 = averaged 0.9 depth samples.

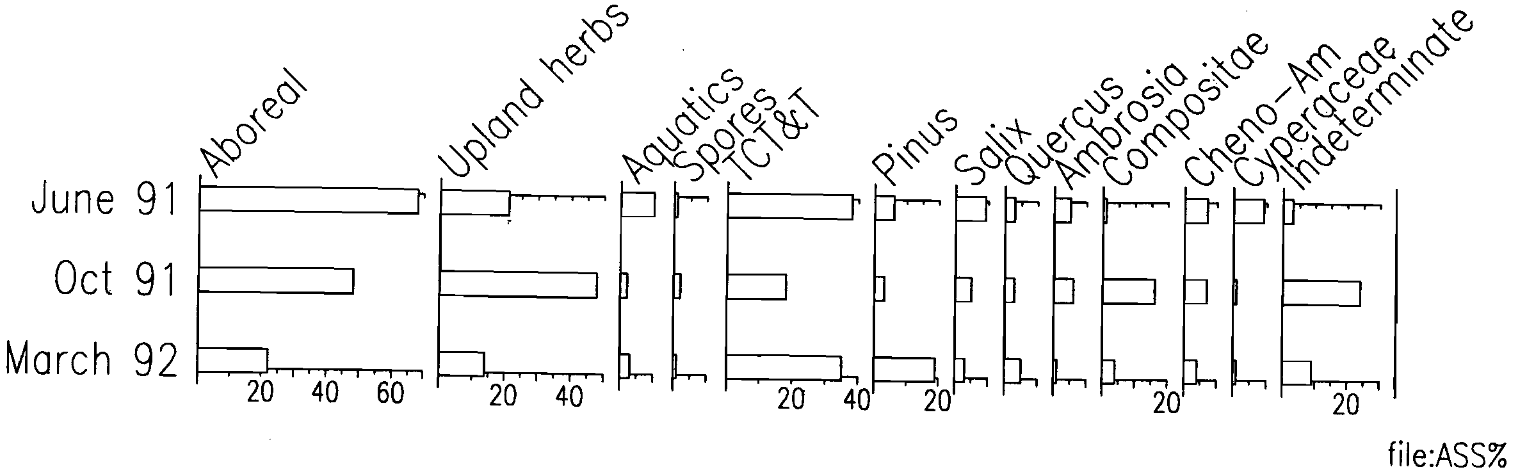

Figure 7. Relative abundance of pollen types as percent of total sum within cross section of the Atchafalaya River at Morgan City, Louisiana, at different seasons.

for each cross section. Seasonal changes in the percentage importance of the different taxa are shown in Figure 7.

Average concentrations of the most abundant taxa vary noticeably from season to season (Figure 5). The highest concentrations of TCT&T, *Salix* and the upland herbs are observed in June. *Pinus* and indeterminate concentrations peak in March. *Quercus* pollen demonstrates nearly equal average concentrations in June and March. The lowest concentrations of all the pollen types are in October. An obvious similarity in vertical distribution of many taxa is a consistent increase in concentration towards the bed in June and March (Figure 6). Concentrations of individual pollen types, with the exception of *Ambrosia*, are significantly related to suspended sediment concentrations (Table 1).

DISCUSSION AND CONCLUSIONS

Seasonal pollen production is an important factor controlling suspended pollen concentrations in the Atchafalaya River. Concentrations of the *Pinus*, *Salix,* and *Quercus* pollen types (Figure 5) generally coincide with their flowering periods in Louisiana. Broken *Pinus* grains constituted in March only 10% of the total *Pinus* pollen. This is assumed to suggest high proportions of local *Pinus* at this time of year (Campbell and Chmura, 1994). On the contrary, in June 30% of *Pinus* pollen was fragmented which suggests that a higher proportion was transported from the upper basin where *Pinus* blooms in April or May (Burns and Honkala, 1990; Campbell and Chmura, 1994).

Pollen concentrations of some herbaceous taxa, such as Compositae and Cyperaceae (Figure 5), only partly reflect flowering seasons of representatives of these families throughout the river basin. The Cyperaceae family is characterized by a somewhat earlier (May-August) blooming period, and this is probably why peak concentrations can be observed in June. The trend of increasing concentrations of Compositae pollen from June to March is in part due to the supply during long blooming period of this extensive group. Over this broad region of the river basin plants of Compositae family bloom from May to December (U.S. Department of Agriculture, 1971) during periods of both high and low discharge. Since the peak concentration in March is prior to the blooming season, these grains must represent a source from the previous year.

Table 1. Coefficients of Pearson correlation (r) and level of significance (P) for pollen and suspended sediment concentrations within the cross section of the Atchafalaya River at Morgan City. Percentages of total pollen sum (%) and concentrations (grains l^{-1}) of the most abundant pollen types in the Atchafalaya at Morgan City (MC) in 1991, and in the Mississippi at Point a la Hache (PH) in 1987.

			June				March			
			MC		PH		MC		PH	
	(r)	P	%	gr l^{-1}	%	gr l^{-1}	%	gr l^{-1}	%	gr l^{-1}
TCT&T	0.80	<0.001	38	1298	4	78	35	792	14	1136
Pinus	0.74	<0.001	6	187	6	108	19	459	7	668
Salix	0.69	<0.001	9	324	3	61	3	66	5	482
Quercus	0.79	<0.001	3	120	12	239	5	118	10	885
Compositae*	0.27	<0.050	7	235	11	213	5	106	13	1258
Cheno-Am	0.67	<0.001	7	256	6	112	4	100	7	742
Cyperaceae	0.70	<0.001	9	334	2	29	1	27	2	193
Indeterminate	0.70	<0.001	3	105	19	363	9	213	23	2196
Total pollen	0.85	<0.001	-	3447	-	1943	-	2263	-	5000
SUM			82	-	63	-	81	-	81	-

*Compositae type includes *Ambrosia*, *Artemisia* and Compositae -Tubuliflorae pollen. Coefficient of correlation for *Ambrosia* type is 0.003; for Compositae -Tubuliflorae is 0.35, P<0.01.

Evidently, it is not possible to explain concentration distribution patterns (Figure 5) solely in terms of pollen production seasonality. Concentrations of TCT&T, *Ambrosia*, and Cheno-Am pollen demonstrate unexpectedly high concentrations in June, while the flowering peak of these plants is either earlier or later in season. The local representative of the TCT&T family, *Taxodium distichum*, blooms in Louisiana in February, while its concentration peaks in June. *Ambrosia* flowers earlier at higher latitudes, so that in southern Louisiana this plant is expected to release its pollen in late September or October while in the upper basin flowering may occur as early as in July. The vertical distribution of *Ambrosia* pollen in October (Figure 6) implies that at this time of year many of the grains were derived from aerial deposition as concentrations in the surface layer were 40% greater than that at mid depth. However, average concentration of *Ambrosia* pollen peaks in June (Figure 5), when neither local nor upstream vegetation is in bloom.

As concentrations of suspended pollen are highly correlated with suspended sediment concentrations, the differences in timing may be brought about by the seasonal geomorphological processes taking place within the river system. Changes in the bottom profile indicate scouring of the river channel, which is especially prominent at the high river stages in June and March (Figure 4). Thus, the general pattern is influenced by variations in river discharge. At periods of high flow, scouring of the river channel and the bottom of the lakes within the lower Atchafalaya Basin occurs (Adams and Baumann, 1980). Resuspended sediment is then transported through the lower Atchafalaya River to the Atchafalaya Bay and offshore areas. Under low flow conditions (discharge below average) sediment deposition occurs within the river basin, reducing pollen in abundance at this time. Seasonal and vertical distribution of suspended sediment load in the present study corroborates this general pattern (Figures 5 and 6).

Comparison of average pollen concentrations for the 0.9 depth to the average for the entire cross section shows that approximately 60% of total pollen load is concentrated at the bed in all seasons (Figure 6). Thus, resuspension plays a critical role in formation of pollen load in the river, a pattern driven by hydrological regime of the river. The resuspension of pollen from the bed is not only important in formation of total pollen load in the Lower Atchafalaya, but can also help to explain seasonal variations in pollen assemblages. The great abundance of the TCT&T pollen which occurs after the blooming peak of *Taxodium distichum* (Figure 5) can be attributed to deposition of this pollen under low flow condition in February which is coincident with the early flowering of *Taxodium*. This reserve of TCT&T pollen is resuspended during conditions of high flows causing increased proportions of TCT&T pollen throughout the year. Likewise, the increased concentrations of Compositae in March and the Cheno-Am and *Ambrosia* pollen types in June can be attributed to resuspension (at the high river stages) of grains previously deposited on lake and river beds. In addition, high surface runoff caused by snow melt in the upstream basin, in March, could result in an increased transport of badly preserved (indeterminable) pollen off the surrounding soils into the flooded fluvial system at this time (Figure 5).

Thus, to understand the distribution and concentration of pollen in a river, one should be concerned with processes of movement and storage of sediment within that system. Pollen load in both the Mississippi (Chmura and Liu, 1990) and Atchafalaya Rivers is significantly correlated with suspended sediment, and demonstrates a positive response to increasing discharge conditions through resuspension of grains previously incorporated into the bed. The same mechanism is expected to be at work in other alluvial channels, due to similarity in the pattern of sediment movement and storage (Meade *et al*., 1990). Pollen production seasons are superimposed on this geomorphological pattern and may increase or reduce the concentrations of pollen in suspension also playing an important role in replenishment of pollen material available for resuspension. Similar processes have been observed in other fluvial systems (Starling and Crowder, 1980; Traverse, 1992).

Examination of the seasonal variation of concentrations of suspended pollen in the Atchafalaya enables a more accurate calculation of the pollen load discharged into the Gulf of Mexico by the Mississippi River system. Calculations of polen discharge (Q_{pollen}) have been performed using a formula:

$$Q_{pollen} = \int_{A} C_{pollen} V_{flow} \, dA$$

where C_{pollen} = the average weighted pollen concentration within a panel with dA area,

V_{flow} = the average flow velocity within the same panel, and A = the cross section area. The calculation shows that total pollen discharges in June and March are two orders of magnitude higher than that in October (Table 2). Individual pollen types demonstrate variable discharges with season. The maximum discharge of *Pinus* and Indeterminate grains is in March while most other taxa have a peak discharge in June. October values are extremely low for almost all the taxa. The nine pollen types which have highest percentage values constitute more than 75% of the total pollen discharge estimate through the cross section at each sampled month.

The yearly pollen discharge was calculated with the assumption that each of the sample times represents a different season of pollen supply. June is assumed to represent the four month period (from June to September) characterized by pollen influx from the local and upstream herbaceous vegetation. October is characteristic of the five month period with low overall pollen production. March reflects the time of intensive pollen production by tree species (March-May). With additional weighing based upon horizontal variations in pollen concentrations over the cross section at each sample time and utilizing the 20-year average discharge calculated for Simmesport, Louisiana (Bahr *et al.*, 1983), yearly pollen discharge through the Lower Atchafalaya and the Wax Lake outlets (Figure 2) is estimated to be $3.2\text{x}10^{17}$ grains yr^{-1}. It is assumed that due to the equal split of the flow between the two outlets, approximately half this amount is transported through the river at Morgan City.

The annual pollen discharge for the Mississippi River at Point a la Hache calculated by Chmura and Liu (1990) was derived from the relationship of pollen and suspended sediment concentrations, which have since been revised. Using corrected data for average annual sediment discharge provided by Meade (USGS, Denver, Colorado) the total pollen load of the Mississippi is calculated to be $4\text{x}10^{18}$ grains yr^{-1}. This is an order of magnitude higher than the estimate for annual pollen discharge to the Gulf of Mexico by the Atchafalaya River ($3.2\text{x}10^{17}$ grains yr^{-1}). This difference might be explained in terms of lower hydrologic discharge as well as lower total pollen concentrations in the Atchafalaya. As pollen discharge calculations for two rivers were based upon different methods, it is difficult to estimate the relative contribution of these parameters to the

Table 2. Total pollen discharge and discharges of the most abundant taxa (grains s^{-1} x10^8) through the cross section of the Atchafalaya River at Morgan City, Louisiana at different seasons.

	June 91	October 91	March 92
TCT&T	92.1	1.02	47.9
Pinus	12.7	0.141	29.3
Salix	23.6	0.284	4.08
Quercus	8.7	0.125	7.49
Ambrosia	13.3	0.298	1.25
Compositae-Tub	3.07	0.978	5.09
Cheno-Am	18.4	0.428	6.03
Cyperaceae	24.1	0.021	1.62
Indeterminate	7.7	1.3	13
Total pollen	252	5.91	140

observed difference. However, since no sampling was performed at the season of the lowest pollen production in the Mississippi River study, the pollen discharge of the Mississippi could be overestimated.

Thus, the Atchafalaya and Mississippi together contribute 4.3×10^{18} grains or 21,000 metric tons (using 4.8×10^{-6} mg grain^{-1}; Brush and Brush, 1972) of pollen yearly into the Gulf of Mexico. Once it enters the Gulf, pollen will probably be transported by local currents westward (Cochrane and Kelly, 1986) and potentially across the Louisiana and Texas shelf. Estimating the Louisiana and Texas shelf area as 1.2×10^{5} km^{2}, the annual influx of pollen from the Mississippi and Atchafalaya Rivers to the shelf would be 3,600 grains cm^{-2} yr^{-1}. Of this total amount 7% is attributed to the Atchafalaya River.

As the Atchafalaya Bay, downstream of Morgan City is a site of active delta growth, pollen may be deposited in the sediments of the incipient delta rather than transported offshore. However, evidence for transport of Atchafalaya pollen to the shelf is provided by Costello (1992) who studied the distribution of pollen in surface (0-2 mm layer) sediments of the Gulf of Mexico. Total pollen concentrations in these sediments ranged from 565 to 19,273 grains cm^{-3} (Figure 8). The station with the highest pollen concentration is located offshore of the Atchafalaya Bay. It is evident from this single peak that the Atchafalaya's pollen load can be detected on the shelf, but it cannot yet be determined as to how widely it is distributed on the shelf. Because the pollen assemblages of the mainstem Mississippi and Atchafalaya are so similar (Table 2), it is difficult to discriminate their relative contribution to the shelf deposits.

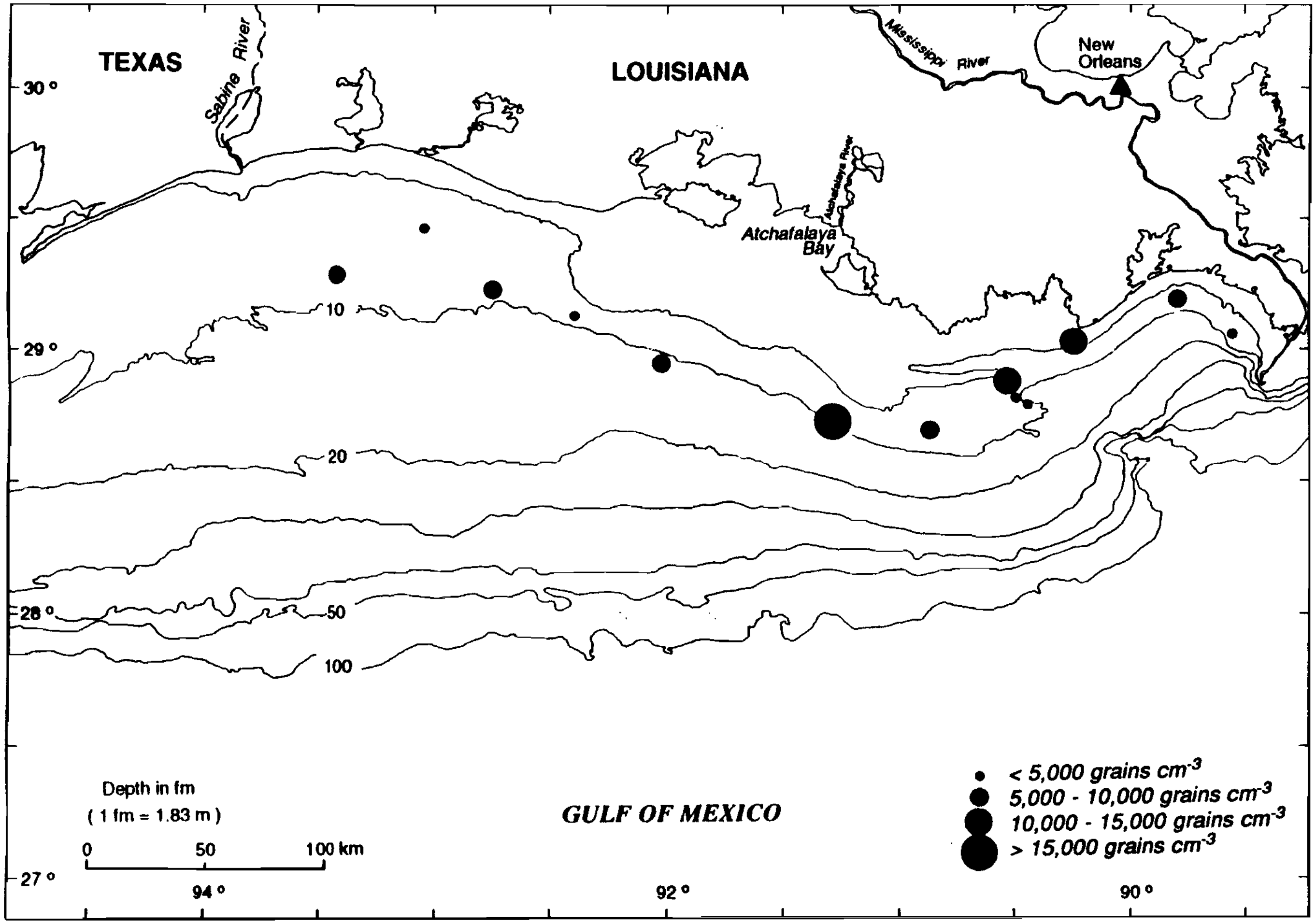

Figure 8. Distribution of pollen in surface (0-2 mm layer) sediments of the Gulf of Mexico on the West Louisiana and Texas Shelf (adapted from Costello, 1992). Base map modified from Chuang and Wiseman (1983).

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CONCLUSIONS

The distribution of suspended pollen load within a river system is shown to be independent of flow dynamics. Thus, based upon processes of transport, differential deposition of grains within alluvial channels should not be expected. As such, pollen from alluvial deposits should provide a useful tool for paleoenvironmental reconstructions, providing that sources of pollen and sediment are known.

Spatial variability in the distribution of suspended pollen in rivers may occur, but in these studies differences were not greater than one order of magnitude. Both spatial and temporal variability are governed by interaction of two factors, pollen production and resuspension of previously deposited grains from the river bed, with relative importance of these controls varying from season to season. The general pattern can conceivably vary for different river systems depending on the abundance and type of local and upstream vegetation as well as availability of pollen grains for resuspension in river sediments.

Pollen influx through the air-water interface and resuspension, acting constantly, can create specific vertical patterns of distribution of suspended pollen load due to insufficient vertical mixing within the river flow. Therefore, one concerned with the sources of pollen supply to a particular river would need to perform point sampling including surface, mid depth, and near-bed points. However, to make a conclusion on the nature of the pollen load transported by a river, depth-integrated or a point sample from intermediate depth would probably be adequate.

The second study also supports previous findings that rivers are important sources of pollen to the marine environment. The estimates of pollen discharge into the Gulf of Mexico developed here can be utilized in creation of a budget model for that region, providing that sedimentation rates at different sites of the shelf are established.

APPENDICES

Appendix 1. Pollen and spore counts from cross section at St. Francisville, Louisiana, in June 1991.

	Acer	*Alnus*	*Ambrosia*	*Artemisia*	*Betula*	*Carya*	*Castanea*	*Celtis*	*Cephalanthus*	Cheno-Am	Compositae-Lig
LS	1	0	9	0	1	0	0	7	0	28	0
L1	0	1	3	0	1	4	0	11	0	21	0
L3	1	0	3	0	1	3	0	3	0	33	1
L5	0	0	1	0	3	2	0	3	0	29	0
L7	0	0	11	0	2	0	0	0	2	33	0
L9	0	0	2	0	0	4	0	12	0	26	0
LCS	0	0	10	0	0	0	0	1	0	34	1
LC1	0	3	2	1	0	9	0	3	0	24	0
LC3	3	0	2	2	2	11	0	2	0	45	0
LC5	0	0	7	0	0	16	0	7	0	31	0
LC7	0	0	4	0	0	0	0	3	0	36	0
LC9	0	0	3	0	1	9	0	11	0	15	1
CS	0	0	0	1	0	0	0	7	0	20	0
C1	0	0	2	0	0	2	0	4	0	36	0
C3	0	1	6	0	0	13	0	3	0	45	0
C5	0	0	1	0	3	2	0	1	0	40	0
C7	1	0	2	1	1	2	1	3	0	31	0
C9	0	0	4	0	0	3	0	5	0	36	0
RCS	1	0	2	0	0	0	0	11	0	26	1
RC1	0	0	2	0	0	0	0	9	0	43	0
RC3	0	0	3	0	5	6	0	5	0	27	0
RC5	0	0	4	0	1	6	0	2	0	19	0
RC7	0	0	1	0	2	3	0	1	0	29	1
RC9	0	0	1	0	0	6	0	1	0	21	0
RS	0	1	2	0	1	1	0	1	0	35	0
R1	0	0	0	0	149	0	0	1	0	13	0
R3	0	0	8	0	1	3	0	5	0	36	1
R5	1	0	3	0	0	4	0	4	0	30	0
R7	0	0	3	0	0	2	0	2	0	26	0
R9	0	0	0	0	0	0	0	1	0	12	0
Total	8	6	101	5	174	111	1	129	2	880	6

Appendix 1. (cont.)

	Compositae-Tub	*Cornus*	*Corylus*	Cyperaceae	*Dryas*	*Equisetum*	*Fraxinus*-3	*Fraxinus*-4	*Galium*	Gramineae	*Juglans*
LS	36	0	0	7	1	0	3	0	0	13	0
L1	36	0	0	7	0	0	6	0	1	4	0
L3	36	0	0	0	0	0	2	0	0	9	0
L5	21	0	0	4	0	0	1	1	0	12	0
L7	18	0	0	9	0	0	3	0	0	9	0
L9	18	0	0	2	1	0	3	0	0	4	0
LCS	14	0	0	10	0	2	3	0	0	19	0
LC1	43	0	0	0	0	0	2	0	0	9	2
LC3	46	0	1	2	0	0	2	0	0	11	0
LC5	16	0	0	0	0	0	0	0	0	0	0
LC7	17	0	0	3	0	0	0	0	0	11	0
LC9	14	0	0	2	0	0	2	0	0	4	0
CS	33	1	0	4	0	0	9	0	0	18	0
C1	36	0	0	1	0	0	3	0	0	16	0
C3	31	0	0	18	0	0	1	0	0	13	0
C5	25	0	0	3	0	0	3	0	0	8	1
C7	19	2	0	1	0	0	1	0	0	12	0
C9	27	0	0	1	0	0	2	0	0	7	0
RCS	29	1	0	7	0	0	6	0	0	7	0
RC1	37	0	0	2	1	0	2	0	0	6	0
RC3	15	0	0	4	0	0	6	0	0	6	0
RC5	21	0	0	2	0	0	1	0	0	5	0
RC7	17	0	0	4	0	0	2	0	0	7	0
RC9	16	0	0	3	0	0	1	0	0	10	0
RS	46	0	0	1	0	0	1	0	1	5	4
R1	20	0	0	0	0	0	0	0	0	1	0
R3	25	0	0	11	0	0	6	0	0	15	0
R5	23	0	1	7	0	0	1	0	0	14	0
R7	17	0	0	1	0	0	0	0	0	14	0
R9	11	0	0	2	0	0	0	0	0	5	0
Total	763	4	2	118	3	2	72	1	2	274	7

Appendix 1. (cont.)

	Liquidambar	*Morus-Urtica*	*Myrica*	*Nuphar*	*Nyssa*	*Ostrya*	*Picea*	*Pinus*	*Pinus strobus*	*Polygala*
LS	0	3	0	0	0	0	0	19	0	0
L1	0	0	0	0	0	4	1	6	0	0
L3	0	0	1	0	0	2	1	12	0	0
L5	0	0	0	0	1	1	5	14	0	0
L7	0	0	0	0	1	0	4	4	0	0
L9	0	0	0	0	0	1	3	8	0	0
LCS	1	0	2	0	0	0	0	16	0	0
LC1	0	0	0	0	0	3	1	13	0	0
LC3	2	1	0	0	0	2	2	9	0	0
LC5	0	0	0	0	0	0	0	7	0	0
LC7	0	0	0	0	0	1	1	8	0	0
LC9	0	0	0	0	0	8	6	11	0	0
CS	0	2	0	1	0	0	1	4	0	0
C1	0	0	0	0	0	3	0	16	0	0
C3	0	3	0	0	0	4	3	8	0	0
C5	0	0	0	0	0	0	3	7	0	0
C7	0	0	0	0	0	1	0	11	1	0
C9	0	0	0	0	0	0	2	13	0	0
RCS	0	1	5	0	0	4	1	2	0	1
RC1	0	0	0	0	0	1	0	8	0	0
RC3	0	1	0	0	0	2	6	1	0	0
RC5	0	0	0	0	0	1	1	10	0	0
RC7	0	1	0	0	0	1	0	7	0	0
RC9	0	0	0	0	0	0	1	13	0	0
RS	0	0	1	0	0	3	1	6	0	0
R1	0	0	0	0	0	0	1	9	0	0
R3	0	1	0	0	1	2	2	6	0	0
R5	0	0	0	0	0	1	3	10	0	0
R7	0	0	0	0	0	0	1	15	0	0
R9	0	0	0	0	0	0	1	12	0	0
Total	3	13	9	1	3	45	51	285	1	1

Appendix 1. (cont.)

	Polygonum aviculare	*Polygonum*	*Populus*	*Potamogeton*	Pyrolaceae	*Quercus*	*Rumex*	Saxifragaceae	*Sagittaria*
LS	0	0	0	0	0	14	0	0	3
L1	0	0	1	0	0	16	0	0	4
L3	0	0	0	0	0	7	0	0	0
L5	0	0	1	1	0	13	0	0	0
L7	0	0	0	0	0	18	0	0	2
L9	0	0	0	0	0	10	0	1	2
LCS	0	0	0	0	0	14	0	0	3
LC1	0	0	0	0	0	13	0	0	1
LC3	0	0	0	0	0	28	0	0	0
LC5	0	0	0	0	0	0	0	0	0
LC7	0	0	0	0	0	5	0	0	1
LC9	0	0	0	0	1	8	0	0	0
CS	0	0	0	0	0	15	0	0	6
C1	0	0	0	0	0	14	0	0	0
C3	0	0	0	0	0	18	0	0	1
C5	0	0	0	0	1	10	0	0	1
C7	1	0	0	0	0	3	0	0	1
C9	0	0	0	0	0	10	0	0	1
RCS	0	0	0	0	0	20	1	0	3
RC1	0	0	1	0	0	4	0	0	3
RC3	0	0	0	0	0	14	0	0	2
RC5	0	0	0	0	0	5	0	0	0
RC7	0	0	0	0	0	5	0	0	0
RC9	0	0	0	0	0	8	0	0	0
RS	0	0	1	0	0	9	0	0	1
R1	0	0	0	0	2	2	0	0	0
R3	0	0	0	0	0	11	0	0	5
R5	0	1	0	0	0	7	0	0	1
R7	0	0	0	0	0	10	0	0	0
R9	0	0	0	0	0	2	0	0	0
Total	1	1	4	1	4	313	1	1	41

Appendix 1. (cont.)

	Salix	*Taxodium*	TCT	*Tilia*	*Typha*-mono	*Ulmus*	Umbelliferae	*Vigna*	monolete-psilate	monolete
LS	10	5	22	0	0	0	3	1	7	3
L1	25	1	8	0	8	0	5	2	0	4
L3	10	1	7	2	0	2	2	2	1	0
L5	7	4	24	0	7	0	1	1	5	2
L7	8	4	17	0	6	0	10	3	2	2
L9	31	6	15	0	2	0	14	0	1	1
LCS	11	8	3	0	0	1	8	1	11	13
LC1	17	3	12	0	1	0	7	4	5	4
LC3	16	5	15	4	4	0	3	0	2	0
LC5	7	0	7	0	0	0	0	0	0	0
LC7	6	2	12	0	1	0	0	0	6	1
LC9	23	4	33	0	4	0	7	0	1	1
CS	19	3	4	0	4	0	8	0	5	22
C1	11	0	20	0	2	0	2	0	0	4
C3	7	1	6	0	10	0	0	1	5	1
C5	11	1	6	1	0	0	4	0	5	3
C7	9	0	12	1	2	1	1	1	3	3
C9	10	2	18	0	2	0	3	0	3	2
RCS	12	9	6	0	2	0	2	2	2	16
RC1	17	0	15	0	2	0	1	1	6	1
RC3	8	1	6	0	3	0	1	1	2	1
RC5	8	2	5	0	2	0	1	0	0	0
RC7	7	1	9	0	4	0	5	1	2	0
RC9	3	0	9	0	0	0	4	0	0	1
RS	16	2	7	0	2	0	4	1	1	1
R1	3	0	6	1	1	0	2	1	0	0
R3	17	4	15	0	2	0	2	1	6	4
R5	14	3	10	0	1	0	3	2	3	0
R7	6	1	7	1	1	0	4	0	0	3
R9	8	1	11	0	2	0	3	0	1	0
Total	351	74	347	10	75	4	110	26	85	93

Appendix 1. (cont.)

	trilete	indeterminate	concealed	unknown	SUM	marker	volume (l)
LS	11	24	1	5	237	2209	0.980
L1	3	16	0	2	201	1772	0.800
L3	0	18	0	1	161	2619	0.980
L5	15	19	0	4	202	3180	0.980
L7	8	18	1	5	200	2647	0.980
L9	7	22	2	6	204	2066	0.980
LCS	0	10	0	4	200	2273	0.740
LC1	5	18	1	1	207	2191	0.800
LC3	0	31	0	3	256	3167	0.980
LC5	7	16	0	0	121	2405	0.900
LC7	8	11	4	1	142	2632	0.980
LC9	7	24	2	6	208	2256	0.800
CS	1	9	2	1	200	1105	0.945
C1	13	23	3	4	215	2348	0.960
C3	0	27	1	3	230	3416	0.980
C5	13	20	5	2	180	2621	0.980
C7	8	12	2	4	154	3088	0.980
C9	9	19	1	2	182	3341	0.975
RCS	9	13	0	2	204	2148	0.945
RC1	2	21	0	1	186	2593	0.980
RC3	5	16	0	0	147	2735	0.965
RC5	5	18	1	4	124	2814	0.940
RC7	7	12	0	3	132	3127	0.900
RC9	8	16	2	3	127	2667	0.945
RS	10	24	0	5	194	2202	0.960
R1	0	10	0	0	222	1532	0.810
R3	2	28	2	5	227	2838	0.980
R5	9	27	2	5	190	2508	0.975
R7	10	21	4	1	150	2826	0.975
R9	13	13	1	2	101	3251	0.980
Total	195	542	37	85	5504	76577	-

Appendix 2. Pollen and spore counts from cross section at Morgan City, Louisiana, in October 1991.

	Acer	*Alnus*	*Ambrosia*	*Artemisia*	*Bacopa*	*Betula*	*Carya*	*Celtis*	*Cephalanthus*	Cheno-Am
LS	0	0	0	1	0	0	0	1	0	4
L1	0	1	25	0	0	0	0	1	0	7
L3	0	0	10	0	1	0	0	1	0	2
L5	0	0	6	0	0	0	2	0	0	6
L7	0	0	7	0	0	0	2	1	0	13
L9	1	1	3	0	0	0	5	0	0	11
LCS	0	0	1	0	0	0	0	1	0	2
LC1	0	0	1	0	0	0	0	0	0	3
LC3	0	0	2	0	0	0	0	1	0	4
LC5	0	0	2	0	0	0	1	0	1	2
LC7	0	0	1	0	0	0	1	1	0	8
LC9	1	0	2	0	0	0	2	1	0	6
CS	0	0	0	0	0	0	1	0	0	1
C1	0	0	14	0	0	0	1	0	0	4
C3	0	0	12	0	0	0	0	0	0	4
C5	0	0	7	0	0	0	0	0	0	3
C7	0	0	12	0	0	0	0	0	0	4
C9	0	0	4	0	0	0	5	0	0	10
RCS	0	0	0	0	0	0	1	0	0	2
RC1	0	0	0	0	0	0	0	1	0	5
RC3	0	0	0	0	0	0	1	0	0	2
RC5	0	0	3	0	0	1	0	0	0	1
RC7	0	1	0	0	0	0	0	0	0	3
RC9	0	0	2	0	0	0	1	4	0	8
RS	0	0	23	0	0	0	1	1	0	3
R1	0	0	1	0	0	0	1	1	0	2
R3	0	0	0	0	0	0	1	0	0	2
R5	0	0	0	0	0	0	1	1	0	3
R7	0	1	1	0	0	0	6	0	0	15
R9	0	1	5	1	0	0	0	2	0	9
Total	2	5	144	2	1	1	33	18	1	149

Appendix 2. (cont.)

	Compositae-Tub	*Cornus*	Cyperaceae	*Dryas*	*Fraxinus-3*	*Galium*	Gramineae	*Juglans*	*Morus-Urtica*	*Myrica*
LS	4	0	0	0	0	0	1	0	0	0
L1	117	0	0	0	1	0	0	0	0	0
L3	15	0	0	0	0	0	0	0	0	0
L5	11	0	1	0	0	0	1	1	1	0
L7	36	0	0	0	1	0	8	0	0	0
L9	14	0	1	0	1	0	6	1	0	1
LCS	2	0	1	0	0	1	2	1	0	0
LC1	3	0	1	0	0	0	0	0	0	0
LC3	5	0	0	0	0	0	0	0	0	0
LC5	2	0	0	0	0	0	0	0	0	0
LC7	6	0	0	0	1	0	4	1	0	0
LC9	11	0	1	1	1	0	4	1	0	0
CS	2	0	0	0	1	0	1	0	0	0
C1	10	0	1	0	0	0	1	0	0	0
C3	31	0	0	0	0	0	1	0	2	0
C5	21	1	0	0	0	0	0	0	0	0
C7	47	0	0	0	1	0	1	1	0	0
C9	28	0	0	0	0	0	0	0	0	0
RCS	3	0	1	0	0	0	2	0	1	0
RC1	6	0	0	0	0	0	1	0	0	0
RC3	0	0	0	0	0	0	0	0	0	0
RC5	0	0	0	0	1	0	2	0	1	0
RC7	2	0	1	1	1	0	5	0	0	0
RC9	4	0	0	0	1	0	1	0	1	0
RS	14	0	0	0	3	0	0	0	1	0
R1	6	0	0	0	0	0	1	0	1	0
R3	2	0	0	0	0	0	0	0	0	0
R5	4	0	0	0	0	0	3	0	0	0
R7	13	0	0	0	0	0	3	0	0	0
R9	14	0	0	1	0	0	5	0	0	0
Total	433	1	8	3	13	1	53	6	8	1

Appendix 2. (cont.)

	Myriophyllum	*Nyssa*	*Ostraya*	*Picea*	*Pinus*	*Polygonum*	*Populus*	*Quercus*	*Sagittaria*	*Salix*
LS	0	1	0	0	1	1	0	0	0	0
L1	0	0	0	0	5	0	0	2	0	2
L3	0	0	0	0	1	0	0	0	0	2
L5	0	0	0	0	4	0	0	2	0	8
L7	0	3	0	0	6	0	0	5	1	10
L9	1	1	1	0	3	0	0	1	0	6
LCS	0	0	0	1	0	0	0	2	0	1
LC1	0	0	0	0	3	0	0	0	0	3
LC3	0	0	0	0	2	0	0	2	0	2
LC5	0	0	0	1	0	0	1	3	2	2
LC7	0	0	0	0	2	0	0	2	0	5
LC9	0	1	0	0	3	0	0	4	0	4
CS	0	0	0	0	2	0	0	1	0	1
C1	0	0	0	0	1	0	0	4	0	2
C3	0	0	0	0	1	0	0	1	0	1
C5	0	1	0	0	2	0	0	3	0	4
C7	0	1	0	0	1	0	0	2	0	3
C9	0	2	0	0	2	0	0	2	0	2
RCS	0	0	0	0	0	0	0	2	0	1
RC1	0	0	0	0	2	0	0	1	0	2
RC3	0	0	0	0	3	0	0	2	0	0
RC5	0	3	0	0	2	0	0	2	0	7
RC7	0	1	0	0	3	0	0	1	1	3
RC9	0	0	0	0	3	0	0	1	0	7
RS	0	0	0	0	3	0	0	0	0	1
R1	0	0	0	0	1	0	0	5	0	3
R3	0	0	0	0	2	0	0	0	0	3
R5	0	0	0	0	0	0	0	3	0	5
R7	1	0	0	0	2	0	0	0	1	3
R9	0	0	0	0	5	0	0	0	0	4
Total	2	14	1	2	65	1	1	53	5	97

Appendix 2. (cont.)

	Taxodium	TCT	*Tilia*	*Typha*-mono	*Typha*-tetrad	*Ulmus*	Umbelliferae	*Vigna*	monolete-psilate	monolete
LS	1	6	0	0	0	0	0	0	1	1
L1	1	4	0	0	0	0	1	0	2	1
L3	3	9	0	0	0	0	0	0	0	1
L5	0	16	0	0	1	0	1	0	0	0
L7	2	27	1	0	0	0	0	0	0	0
L9	2	25	0	1	0	0	1	0	4	0
LCS	3	7	0	0	0	0	0	0	0	0
LC1	1	11	0	0	0	0	0	0	0	3
LC3	1	5	0	0	0	0	0	0	0	0
LC5	0	10	0	0	0	0	0	0	0	1
LC7	0	13	0	0	0	0	0	0	0	0
LC9	2	10	0	1	0	0	0	0	1	0
CS	4	3	0	0	0	0	0	0	2	0
C1	0	12	0	0	0	0	0	0	0	1
C3	6	19	0	0	0	0	0	0	0	1
C5	0	10	0	0	0	0	0	0	1	2
C7	0	14	0	0	0	0	0	0	0	1
C9	1	12	0	0	0	0	0	0	1	0
RCS	2	5	0	0	0	1	0	0	0	0
RC1	1	10	0	0	0	0	0	0	0	0
RC3	1	4	0	0	0	0	0	0	0	0
RC5	2	7	0	1	0	0	0	0	0	0
RC7	1	9	0	0	0	0	0	0	0	0
RC9	0	10	0	0	0	0	5	0	2	0
RS	0	13	0	0	0	0	0	0	0	1
R1	1	9	0	0	0	0	0	0	0	1
R3	1	3	0	0	0	0	0	0	0	2
R5	2	5	0	1	0	0	1	0	1	0
R7	0	18	0	0	0	0	2	0	0	0
R9	2	14	0	0	0	0	1	1	4	1
Total	40	320	1	4	1	1	12	1	19	17

Appendix 2. (cont.)

	trilete	indeterminate	concealed	unknown	SUM	marker	volume
LS	7	5	1	0	36	2179	0.970
L1	6	7	7	5	195	2583	0.980
L3	7	7	2	1	62	2301	0.965
L5	9	13	1	6	90	2158	0.975
L7	10	13	6	4	156	2346	0.975
L9	17	21	3	1	133	2245	0.970
LCS	8	12	1	0	46	2257	0.970
LC1	7	5	0	3	44	2567	0.975
LC3	6	0	0	0	30	2750	0.980
LC5	12	5	0	1	46	2706	0.960
LC7	11	8	4	2	70	2712	0.980
LC9	6	11	3	1	78	2699	0.950
CS	7	2	0	0	28	2450	0.950
C1	2	5	3	1	62	2503	0.925
C3	9	9	5	1	103	2688	0.945
C5	3	10	1	2	71	2725	0.970
C7	2	9	5	4	108	2761	0.970
C9	8	12	4	1	94	2753	0.950
RCS	11	10	1	0	43	2353	0.955
RC1	3	6	4	1	43	2307	0.960
RC3	7	6	1	0	27	2674	0.960
RC5	4	5	5	1	48	2764	0.970
RC7	7	10	7	1	58	2814	0.955
RC9	10	6	0	2	68	2736	0.930
RS	6	15	3	0	88	2216	0.950
R1	13	5	1	3	55	2732	0.910
R3	16	4	0	0	36	2784	0.970
R5	4	3	4	1	42	2818	0.975
R7	8	6	6	0	86	2912	0.980
R9	5	16	4	1	96	2393	0.985
Total	231	246	82	43	2142	76886	-

Appendix 3. Pollen and spore counts from cross section at Morgan City, Louisiana, in March 1992.

	Acer	*Alnus*	*Ambrosia*	*Artemisia*	*Bacopa*	*Carya*	*Celtis*	Cheno-Am	Compositae-Lig	Compositae-Tub
LS	0	0	1	0	1	0	0	10	0	10
L1	0	1	3	1	4	1	1	11	0	11
L3	0	0	3	0	0	7	1	11	0	18
L5	0	0	1	0	1	5	0	16	0	8
L7	0	0	6	0	0	4	1	11	0	7
L9	0	1	1	0	0	6	0	2	0	4
LCS	0	0	1	0	0	3	2	8	0	6
LC1	0	1	4	0	0	0	0	13	0	8
LC3	0	0	0	0	1	0	3	15	0	3
LC5	0	1	2	0	0	5	1	8	0	8
LC7	0	0	1	0	0	2	1	9	0	9
LC9	1	0	1	0	0	4	2	10	0	7
CS	0	0	2	0	0	4	3	5	0	5
C1	0	0	2	0	0	4	2	7	0	7
C3	1	0	2	0	0	3	3	11	0	9
C5	0	0	1	0	1	3	0	13	0	8
C7	0	0	1	0	1	2	2	6	0	10
C9	0	0	0	0	3	7	5	4	0	1
RCS	0	0	5	0	0	2	3	6	0	4
RC1	0	0	3	0	0	5	0	7	0	6
RC3	0	0	4	0	1	0	2	14	0	12
RC5	0	0	8	0	0	3	0	17	0	9
RC7	0	0	0	0	0	2	1	13	0	9
RC9	0	0	2	0	0	4	1	8	0	9
RS	0	0	5	0	0	8	1	5	0	13
R1	0	2	4	0	0	4	7	16	0	5
R3	0	0	1	0	0	5	2	8	0	7
R5	0	0	0	0	0	1	3	8	1	16
R7	0	1	1	0	0	3	1	6	1	6
R9	0	3	3	0	0	6	3	5	2	10
Total	2	10	68	1	13	103	51	283	4	245

Appendix 3. (cont.)

	Cornus	*Corylus*	Cyperaceae	*Equisetum*	*Fraxinus*-3	*Fraxinus*-4	Gramineae	*Morus-Urtica*	*Myriophyllum*	*Nyssa*
LS	0	1	4	0	3	0	0	0	0	0
L1	0	2	6	0	0	2	1	0	0	0
L3	0	4	4	0	6	0	0	0	0	0
L5	1	0	7	0	5	0	5	0	0	0
L7	5	0	4	0	6	5	3	0	0	1
L9	0	1	2	0	3	1	2	0	0	0
LCS	2	1	5	0	3	1	2	0	0	2
LC1	0	1	1	0	3	1	3	0	1	1
LC3	2	0	2	0	1	0	8	0	0	0
LC5	0	0	4	0	0	1	5	0	0	0
LC7	3	0	4	0	4	2	4	1	0	0
LC9	3	0	1	2	4	1	4	0	0	0
CS	1	0	2	0	4	2	8	0	0	0
C1	0	0	1	2	2	1	3	0	0	0
C3	1	0	3	0	4	4	3	0	0	0
C5	1	2	1	0	3	5	1	0	0	1
C7	0	0	2	0	3	4	5	0	0	0
C9	1	0	0	1	4	2	3	0	0	0
RCS	0	1	2	3	2	1	3	0	0	0
RC1	2	0	4	1	2	3	5	1	0	0
RC3	4	2	0	0	2	1	4	0	0	0
RC5	1	1	0	1	3	1	4	0	0	0
RC7	0	1	4	1	2	1	1	0	0	0
RC9	5	1	2	0	5	3	5	0	0	0
RS	2	1	0	0	6	2	0	0	0	2
R1	0	2	2	1	7	2	7	1	0	0
R3	2	2	4	0	5	3	7	0	0	0
R5	1	0	3	0	4	7	8	0	0	0
R7	0	4	1	0	4	5	0	1	0	0
R9	0	0	0	2	4	4	3	0	0	0
Total	37	27	75	14	104	65	107	4	1	7

Appendix 3. (cont.)

	Pinus	*Polygonum*	*Populus*	*Prunus*	*Quercus*	Rosaceae	*Salix*	*Taxodium*	TCT	*Typha*-tetrad	*Ulmus*
LS	46	4	0	0	14	2	16	17	48	0	1
L1	56	0	0	0	10	5	11	10	30	0	16
L3	62	0	0	0	18	1	14	10	37	0	2
L5	63	0	0	0	11	0	17	7	41	0	0
L7	44	0	0	0	12	3	5	10	43	0	0
L9	94	0	0	0	7	2	3	7	34	0	0
LCS	19	0	0	0	5	4	6	17	60	0	3
LC1	39	0	0	0	14	2	4	9	55	0	2
LC3	32	0	1	0	13	4	9	12	66	0	0
LC5	34	0	0	0	8	0	4	20	74	0	0
LC7	33	0	0	1	15	1	6	18	54	0	2
LC9	28	0	0	0	16	1	6	29	64	0	0
CS	44	0	0	0	18	1	9	16	39	0	1
C1	47	0	0	0	9	2	2	28	50	0	5
C3	50	0	0	0	9	3	7	24	47	0	1
C5	43	0	0	0	8	2	4	24	66	0	0
C7	44	0	0	0	9	2	5	21	54	0	1
C9	38	0	0	0	16	3	6	24	59	0	1
RCS	37	0	0	0	7	0	7	23	71	1	2
RC1	43	0	1	0	6	2	4	25	59	0	0
RC3	35	0	0	0	10	1	2	21	62	0	1
RC5	33	0	0	0	5	4	5	21	62	0	0
RC7	34	0	0	0	13	2	5	22	85	0	2
RC9	45	0	0	0	17	2	8	20	80	0	2
RS	38	0	0	0	7	0	4	14	50	0	6
R1	36	0	0	0	14	3	6	19	46	0	1
R3	40	0	0	0	11	3	6	17	54	0	3
R5	28	0	0	0	11	0	7	17	60	0	3
R7	25	0	0	0	11	1	1	16	80	0	1
R9	23	1	0	0	12	0	8	15	74	0	1
Total	1233	5	2	1	336	56	197	533	1704	1	57

Appendix 3. (cont.)

	Umbeliferae	*Vigna*	Euphorbiaceae	monolete-psilate	monolete	trilete	indeterminate	concealed	unknown	SUM	marker	volume(l)
LS	0	3	1	1	0	3	26	10	0	222	2058	0.925
L1	0	2	0	0	2	7	14	3	3	213	2582	0.980
L3	3	0	0	0	1	11	16	3	8	240	1667	0.910
L5	2	2	0	1	0	1	20	0	4	218	1350	0.790
L7	5	0	0	1	2	7	18	1	7	211	2258	0.640
L9	2	1	0	1	1	3	21	2	6	207	583	0.875
LCS	2	2	0	4	3	5	22	9	5	202	1365	0.870
LC1	0	0	0	0	1	6	22	5	4	200	1098	0.880
LC3	1	1	0	2	1	10	18	0	5	210	1292	0.810
LC5	1	1	0	1	1	7	15	2	6	209	1181	0.840
LC7	4	2	0	4	2	4	12	5	5	208	1614	0.650
LC9	2	1	0	0	0	8	10	2	1	208	940	0.755
CS	2	3	0	5	0	7	16	7	4	208	2338	0.910
C1	2	2	0	1	2	5	12	5	3	206	1509	0.805
C3	2	3	0	1	0	4	11	2	6	214	1520	0.805
C5	1	1	0	4	1	3	11	1	4	213	1714	0.735
C7	2	0	0	2	1	6	10	2	5	200	1469	0.505
C9	0	0	0	1	0	1	18	7	3	208	2083	0.615
RCS	4	0	0	0	2	3	12	8	1	210	1565	0.900
RC1	4	0	0	3	2	6	10	3	5	212	1691	0.680
RC3	1	1	0	4	0	6	9	1	2	202	1670	0.745
RC5	0	1	0	4	2	6	12	6	2	211	2103	0.635
RC7	0	0	0	6	0	5	19	1	3	232	1558	0.730
RC9	1	2	0	4	1	2	10	3	6	248	1315	0.745
RS	2	1	0	1	1	4	14	10	6	203	1691	0.830
R1	1	0	0	5	1	5	15	3	4	219	731	0.975
R3	1	0	0	3	2	3	14	5	4	212	879	0.915
R5	1	1	0	1	3	1	15	4	5	209	1957	0.975
R7	1	1	0	3	4	7	10	8	3	206	1848	0.910
R9	1	4	0	3	0	3	17	9	2	218	2308	0.980
Total	48	35	1	66	36	149	449	127	122	6379	47937	-