United States
Environmental Protection
Agency

Environmental Research
Laboratory
Gulf Breeze FL 32561

Middle Atlantic Region 3
6th and Walnut Sts
Philadelphia PA 19106

Research and Development

EPA

Chesapeake Bay Program

EPA 600/8-80-040
JUNE 1980

BIOSTRATIGRAPHY OF CHESAPEAKE BAY AND ITS TRIBUTARIES
A Feasibility Study

EPA 600/8-80-040
JUNE 1980

BIOSTRATIGRAPHY OF CHESAPEAKE BAY AND ITS TRIBUTARIES
A Feasibility Study

by

Grace S. Brush, Frank W. Davis, and Sherri Rumer,
Department of Geography and Environmental Engineering
The Johns Hopkins University
Baltimore, Maryland 21218

Grant Number R 805962

Thomas Nugent, Project Officer
Chesapeake Bay Program
U. S. Environmental Protection Agency
Mid-Atlantic Region III
and
Office of Research and Development
2083 West Street
Annapolis, Maryland 21401

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the "SPECIAL" REPORTS series. This series is reserved for reports targeted to meet the technical information needs of specific user groups. The series includes problem-oriented reports, research application reports, and executive summary documents. Examples include state-of-the-art analyses, technology assessments, design manuals, user manuals, and reports on the results of major research and development efforts.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

U.S. ENVIRONMENTAL PROTECTION AGENCY

CHESAPEAKE BAY PROGRAM

In response to Congressional directive, the U.S. Environmental Protection Agency established the Chesapeake Bay Program (CBP) to conduct an in-depth study of the Chesapeake Bay and its resources. The Program was initiated in 1976 as a five-year, $25,000,000 program to conduct interdependent scientific and management investigations addressing the environmental quality of the Chesapeake Bay. Major responsibilities are defined as follows:

- o to assess the principal factors having adverse environmental impact,
- o to direct and coordinate research and abatement programs,
- o to collect research data and institute a monitoring program, and
- o to define Bay management structures

Within EPA, the Chesapeake Bay Program is a coordinated effort between the Office of Research and Development and the Mid-Atlantic Region III Office and is administered from a field station in Annapolis, Maryland.

Initial CBP efforts established strong working relationships with the Bay area States, the scientific community and the citizenry. The Program involves active participation from Maryland, Virginia, Pennsylvania and Bay region citizens.

Programs are underway to research toxic substances, submerged aquatic vegetation (SAV), eutrophication (excessive enrichment), and environmental management. To support all Program efforts, including the interpretation of data, computer modeling, and long-term data storage and retrieval a data management system capable of meeting CBP needs is being developed.

The products of the four program areas will provide important tools aiding in defining management alternatives to improve the environmental quality of the Chesapeake Bay. Citizens, managers, scientists and Bay users will all input to the development of alternative control strategies. The coordinated efforts of the Chesapeake Bay Program provides a foundation of interdependent scientific and management criterion important to managing the environmental health of the Chesapeake Bay.

DISCLAIMER

This report has been reviewed by the Chesapeake Bay Program, U. S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U. S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FORWARD

A major objective of the Chesapeake Bay Program submerged aquatic vegetation study is to ascertain if a decline in baygrass populations has occurred over time and if natural population cycles can be identified. The biostratigraphic technique may represent a tool by which submerged aquatic seeds can be detected in bottom cores and through presence/absence seed analysis, aquatic plant cycles identified.

This project was conducted to demonstrate the feasibility of this approach and to develop preliminary information concerning the historical trends of aquatic grass populations in the Chesapeake Bay.

ABSTRACT

Seeds of submerged aquatic vegetation (SAV), diatoms and pollen of terrestrial plants, extracted from sedimentary cores 1 to 1.4 m long in estuarine tributaries, yield information regarding changes in SAV populations, eutrophication and sedimentation since European settlement.

Cores taken from undisturbed depositional areas represent regional conditions with respect to eutrophication and sedimentation, because diatoms and pollen are affected by estuarine transport processes in such a manner that local patchiness is erased but regional differences are not obliterated. Vertical (historical) changes in diatom and pollen distributions therefore can be described for a whole region with only a few cores because the data from one sample at a locale is representative of the whole locale.

SAV seeds, however, are not transported as far because they are larger and are less buoyant. Hence their spatial distributions are highly variable, representing local rather than regional populations. In reconstructing the history of SAV, this requires that a few locales where environmental changes are well documented be studied in detail, thus allowing generalizations about the effect on SAV populations of changes in turbidity and water chemistry.

SAV seeds extracted from cores in the Upper Bay, even though highly variable, consistently reflect the demise of SAV after the 1972 Hurricane Agnes and show major changes in populations of some species since European settlement.

Pollen of terrestrial plants extracted from 12 cores in five tributaries and one from the Bay proper indicate that sedimentation rates vary from approximately 0.2 cm/yr to approximately 2 cm/yr between cores in different areas, and vary within a core from 0.3 cm/yr to 1.9 cm/yr, indicating a high degree of variability in sedimentation rates both spatially and temporally. This variability appears to be related to land use but is influenced also by the size of the drainage area and the morphometry of the tributary.

Diatoms extracted from cores in the Upper Chesapeake Bay show a decrease in the total number of taxa, the number of epiphytic species, and in abundance with the onset of agriculture. The number of species preferring organically enriched water increased from the 1820's to the present, reflecting the influence of increased human occupation of the watershed on the aquatic environment.

CONTENTS

FIGURES

(Continued)

FIGURES (Continued)

(Continued)

FIGURES (Continued)

ACKNOWLEDGMENTS

Dr. Owen Bricker and Robert M. Summers assisted us in collecting the sedimentary cores. Ed Schiemer helped to improvise the coring device for estuarine sediments. Richard Maldeis provided us with vegetation data from Leeds Creek and also contributed to field work in Eastern Bay. Peter Christie assisted in seed identifications, particularly in the Leeds Creek Study. James Stasz assisted in diatom extraction, identification and enumeration.

We thank Dr. Ruth Patrick for inviting one of us (SR) to her laboratory for a short course in diatom taxonomy and ecology.

TABLES

SECTION 1

INTRODUCTION AND OBJECTIVES

INTRODUCTION

The vegetation occupying a watershed, its land use, and the transport and rate of sediment deposition have an important influence on the biological and chemical composition of the receiving water body, determining in large measure the amount and frequency of runoff, chemical and nutrient input and turbidity. Any assessment of the effects of current land use, runoff and sedimentation is difficult to evaluate without comparing present land use and existing biological and chemical conditions of the estuary with land use prior to human disturbance.

There are very few historical data, unfortunately, that can be used for such comparative studies. Even where biological and chemical parameters have been monitored, standard procedures have not been used in all cases; coverage has been limited to a few specific problem areas and in very few instances have the data been collected for more than a decade. Even where the records are reasonably complete for a particular tributary, the information cannot be generalized to all other tributaries because the soils and drainage of the watershed and the morphometry of the tributary are specific to the tributary and its watershed. Very few tributaries are sufficiently similar so that interpretations based upon data collected from one can be applied to others, much less to the main stem of the Bay.

Nevertheless, a compilation of changes or trends in watershed use and the biology and chemistry of tributaries over long time intervals would provide an overall view of the effects of watershed use on the estuarine system and would indicate whether present conditions are unique, a repetition of recurrent conditions or are continuous with the past.

Although historical records are not adequate for such an evaluation, the stratigraphic method can be used to provide such a data base. The stratigraphic method is valuable also because the sediments can extend the record beyond the time of human settlement so that it is possible to compare conditions in the aquatic environment before and after human occupation of the watershed.

The stratigraphic method should be feasible for compiling long historical records of the Chesapeake Bay because the Bay and its tributaries are depositional basins in which are entrapped and preserved some aquatic organisms (e.g., diatoms, cladocerans), parts of organisms (e.g., sponge spicules, pollen and seeds of terrestrial and aquatic plants) and metabolic products of organisms (e.g., chlorophyll degradation products, amino acids). These fossil organisms and remains of organisms represent a portion of the estuarine biota at the time of deposition. Historical changes in the composition of the biota as well as in biomass can be quantified by identifying and enumerating the fossil remains. Thus changes in the presence or absence and in the species composition of submerged aquatics preserved at different stratigraphic horizons represent changes in Submerged Aquatic Vegetation (SAV) at the time of deposition. Similarly, changes in concentrations of chlorophyll products where preserved can yield estimates of biomass or productivity and hence are potential indicators of eutrophic conditions. Changes in species composition and quantity of algae that lend themselves to preservation also provide quantitative data on eutrophication and water quality because many of those species are sensitive to changes in water chemistry. Changes in terrestrial pollen composition are an indicator of watershed land use, e.g., a change from high percentages of oak to high percentages of ragweed pollen indicates that the land has been cleared of forests. In many watersheds this results in increased runoff. Such changes in terrestrial pollen composition can be dated from historical records. Sedimentation rates can then be calculated from dated sedimentary horizons to provide a measure of turbidity and siltation at different times. Rates of sedimentation are necessary also for calculating the quantity of organisms deposited per unit time.

In addition to providing sedimentation rates, pollen of terrestrial plants can be used to measure the distance some sediment is transported in estuaries. Pollen, as a particle, falls within the range of Stokes law of resistance and can be expected to behave similarly in water to particles with small Reynolds numbers, such as fine-grained sand and silt. Where the vegetation adjacent to the river differs fundamentally in generic composition with distance downstream, the pollen produced by these different genera can be considered labeled particles because they are distinguishable. Direct measurements can be made of the distance these pollen grains are moved in the tributary from their source by observing their distributions in the surface sediments. One can infer that particles similar hydrodynamically will be transported approximately the same distance.

The path, distance and rate of sediment transport and deposition provide necessary information for estimating the rate of transport and ultimate fate of toxic and other substances that associate with fine-grained sediments in the aquatic environment.

The stratigraphic method has met with reasonable success in describing the effects of land use and human disturbance on lakes (e.g., Davis 1973, Birks et al. 1976, Brugam 1977). The results, however, are complicated due to variations imposed by differential sedimentation (Davis 1973, Davis and Brubaker 1973). Similar studies have not been carried out for reconstructing the history of estuarine systems even though estuaries too are depositional basins. However, estuaries differ from lakes because the sediment is transported fluvially, and stratigraphic interpretations must take into account the dynamics of estuarine transport.

This study was undertaken to investigate the feasibility of the stratigraphic method for describing changes in SAV, eutrophication and sedimentation rates in the Chesapeake Bay estuary over long periods of time.

OBJECTIVES

The objectives of the study were:

1. to identify the organisms and parts or products of organisms that are the best fossil indicators of SAV and eutrophication by observing which fossils are present most consistently from cores taken in several tributaries, and to identify the changes in pollen populations that would serve to date stratigraphic horizons;

2. to determine the number of cores necessary for obtaining representative data by observing variations in spatial distributions in closely spaced samples taken in surface sediments of the fossils chosen as indicators;

3. to determine whether or not there are preferable depositional zones for different fossils; and

4. to define the resolution of the information with regard to the spatial area represented by a core (or series of cores) taken at a location by studying one area in some detail.

The manner in which each of these questions is addressed is described in the following sections on Submerged Aquatic Vegetation, Sediment Transport and Deposition Rates, and Eutrophication. Laboratory methods that are the same as those described in the Quality Assurance report for this project are not repeated here. However, methods which have been modified are described in Appendix A.

SECTION 2

CONCLUSIONS AND DISCUSSIONS

The record left by organisms and parts of organisms in estuarine sediments is sufficiently complete to provide adequate data for reconstructing some of the chemical, physical and biological conditions of the estuary over long time intervals. The fossils used as indicators of these parameters must be chosen carefully in terms of their ability to preserve, their sensitivity to environmental change, and the knowledge of their ecology. Once a particular indicator is chosen, sampling design must take into account the variability characteristic of the population it represents and the effects of estuarine transport processes on its final distribution in the sediments. Core locations must be selected also from areas of undisturbed deposition so that the historical record is not distorted by scouring, erosion and mixing, including resuspension and bioturbation.

In this study we attempted to identify the fossil indicators and establish sampling designs to describe regional trends or changes over long time periods in SAV, eutrophication and sedimentation rates. In order to accomplish this objective, we used the Upper Chesapeake Bay as a study area because it has a diverse depositional environment, thereby allowing us to compare the biostratigraphy of different depositional basins in the same area.

The best fossil representatives of SAV are seeds; diatoms are a useful indicator of chemical and eutrophic conditions. Pollen of terrestrial plants are used to date stratigraphic horizons in order to obtain sedimentation rates and to calculate seed and diatom flux. The sediments also contain fossil indicators of other populations, e.g., species of sponges and carapaces of cladocerans. These populations can provide information with regard to salinity and the biology of the water. A more detailed and complete history can be compiled by studying fossils of a greater number of different populations. However, since the analysis of a sedimentary core is time-consuming, careful consideration should be given to the kind of information being sought and to the knowledge of the ecology of the organisms represented by the fossils. If nothing is known of the existing distributions and ecological requirements of a particular organisms, it will be difficult to interpret fossil distributions in terms of their response to environmental change until their present day distributions, requirements and limitations are understood.

Sedimentary layers dated thus far by pollen analyses indicate that the sedimentation rates vary from 0.15 cm/yr to approximately 2 cm/yr. A comparison of pollen distributions in surface sediments with distributions of trees in a wide band adjacent to an estuary sampled for pollen suggest that estuarine processes disperse the pollen in the estuary to a greater or lesser extent depending upon the settling velocities of the individual grains. ~~Estuarine dispersion serves to erase some of the local variation~~ due to patchiness of tree distributions, uneveness of pollen production, etc. that were not eliminated by atmospheric dispersion, but it ~~does not mask regional distributions of vegetation~~. Since pollen behaves in water similarly to particles with small Reynolds numbers such as silt and clay, results suggest that fine-grained sediments are transported similarly within the estuary. That is, sediments are not likely to move very far from their source, except when and where conditions are extremely turbulent, such as during intense storms and at the mouths of the tributaries. Consequently, in most cases, it can be expected that ~~sedimentation rates are governed by drainage area and local land use~~. Our data, though preliminary, substantiate this expectation. The large degree of variation in sedimentation rates between cores suggests that local sediment inputs are not homogenized into an even deposition of sediment throughout a tributary. Within the cores we have studied, sedimentation rates are much higher during agricultural periods in tributaries with large drainage areas than in tributaries draining small areas; in the latter, there is little fluctuation in rates.

The above observations are preliminary in that they are based upon data from a total of 12 cores from five tributaries and one core from the Bay proper. It is necessary to measure the rates in most of the major tributaries in order to delineate the importance of all factors involved in the transport and deposition of sediment in the estuary as precisely as possible.

The ~~similarity in vertical diatom assemblages~~ between cores taken in ~~Susquehanna Flats and Furnace Bay~~ indicates that ~~water quality is governed by regional conditions in the watershed~~. The settling velocities of diatoms are such that it is unlikely the populations of the two areas are mixed. More likely, they represent in situ populations which may have been transported short distances within each area. Susquehanna Flats and Furnace Bay are quite different from each other hydrologically. However, water chemistry in both areas is probably influenced more by the character and use of the watershed and therefore may be similar in both places. The diatoms, which are sensitive to water chemistry, appear to be responding predominantly to a more regional pattern of water quality. Thus, we can expect to obtain historical data representative of the effect of watershed use on regional water quality by studying vertical diatom distributions in one or two cores from a good depositional area.

The ~~dissimilarity between vertical profiles of SAV seeds in cores~~ from Susquehanna Flats and Furnace Bay as well as the ~~variability between cores~~ within each area recognizes the ~~high degree of patchiness~~ characteristic of SAV. SAV is represented best in the sediments by seeds. Because of their size (1 to 3 mm) and low buoyancy, they usually are not transported far from the parent beds. Since these beds can change position from year to year, they are characterized by a temporal patchiness as well as spatial patchiness. In contrast to diatoms and pollen, the variability that characterizes SAV and the ineffectiveness of transport processes to erase this local variability requires that a few strategic locations, where specific impacts are documented clearly, be sampled intensively. Past regional conditions can then be inferred from observations of changes in populations in a few areas that are obtained from a sufficient number of samples that regional changes can be separated from natural variability and local effects.

SECTION 3

STUDY AREA

Cores were extracted from Eastern Bay, Hungar's Creek, Susquehanna Flats and Furnace Bay (Figure 1). The decision was made to do a detailed study of one area in order to determine the resolution of the information contained in the sediments. After examining cores from all of the areas listed above, the Susquehanna Flats-Furnace Bay area in the Upper Chesapeake Bay was chosen because depositionally it comprises two entirely different zones: one an undisturbed depositional basin and the other a zone characterized by scouring and redeposition. This study was to determine whether the history of changes in SAV, eutrophication, and sedimentation in the Susquehanna Flats and the Upper Chesapeake Bay--where the depositional history is complicated by scouring and redeposition--would be reflected accurately in a small embayment such as Furnace Bay, where the sediments once deposited remain essentially undisturbed..

DESCRIPTION

The Susquehanna Flats is a broad shallow estuary of roughly 90 km^2 located at the juncture of the Susquehanna River and Chesapeake Bay (Figure 2).

The average depth of water at mean low tide is 1.2 m. The Flats are influenced very little by the tide and receive a large freshwater flow from the Susquehanna River. Consequently, the water is essentially fresh except during very dry periods. High flows from the Susquehanna River during storms result in periodic scouring and redeposition of sediments. Since the Flats are dominated by the Susquehanna River, their history should reflect the historical effects of events in the Susquehanna watershed or, at least some part, on the water of the Upper Bay.

Furnace Bay is a small embayment on the northern edge of the Susquehanna Flats and is fed by Principco Creek (Figure 3). Unlike the Susquehanna Flats, it is an excellent depositional basin with a substrate consisting entirely of silt and clay. It experiences minimal scouring and redeposition. The eastern side of Furnace Bay's watershed is forested to a larger extent than the western side which is cleared mostly for agriculture (Figure 3). The water is uniformly shallow, never deeper than 2 m. Furnace Bay may be somewhat more enriched than Susquehanna Flats because of local sewage discharge into Mill Creek and subsequently into Furnace Bay.

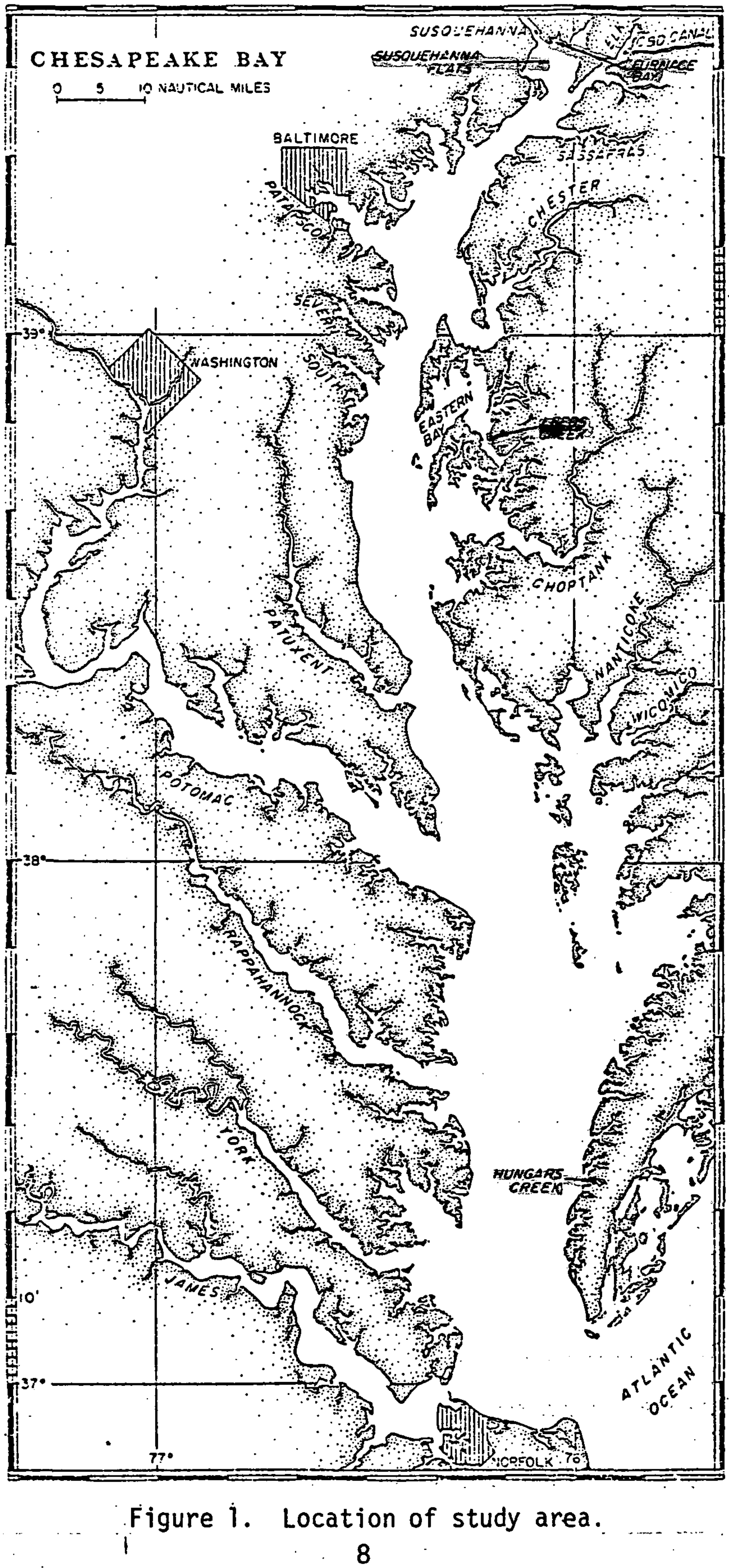


Figure 1. Location of study area.

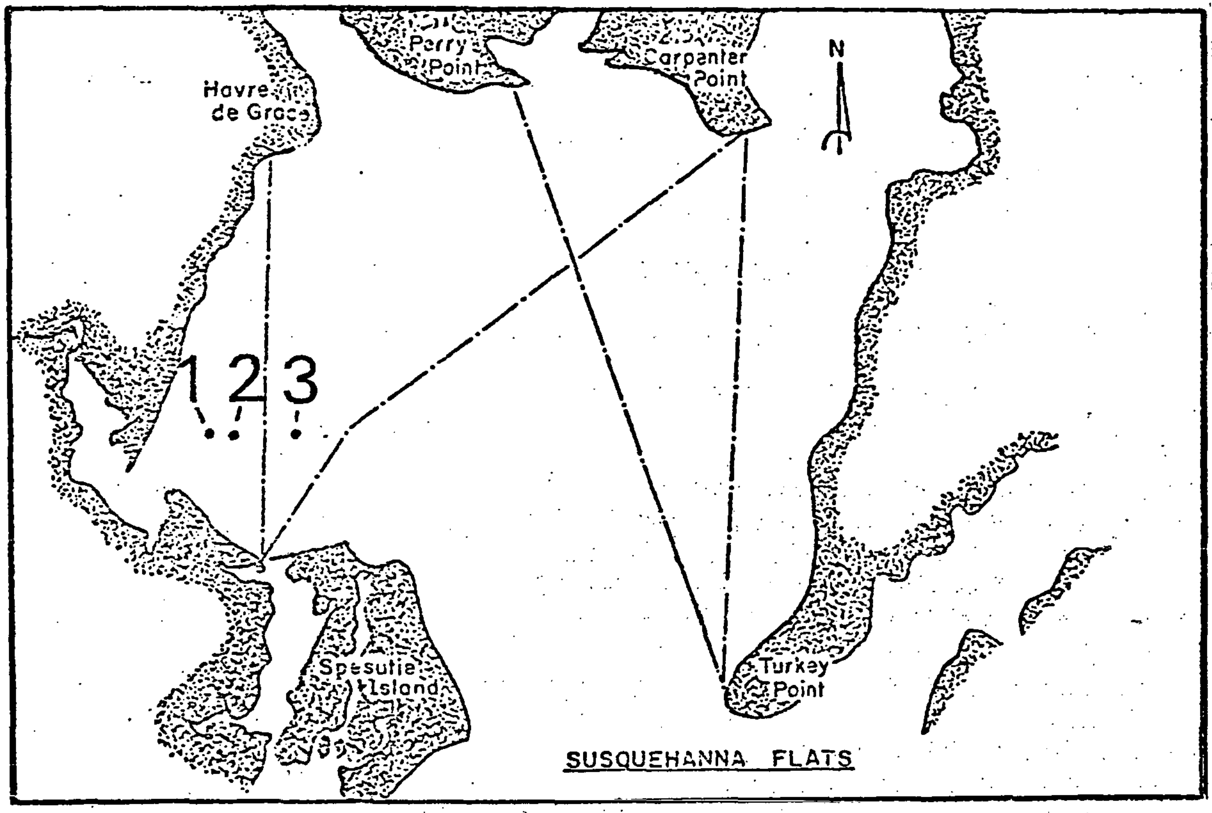


Figure 2. Locations of cores taken in Susquehanna Flats (map from Bayley et al., unpublished manuscript). Broken lines represent MBHRL SAV survey transects.

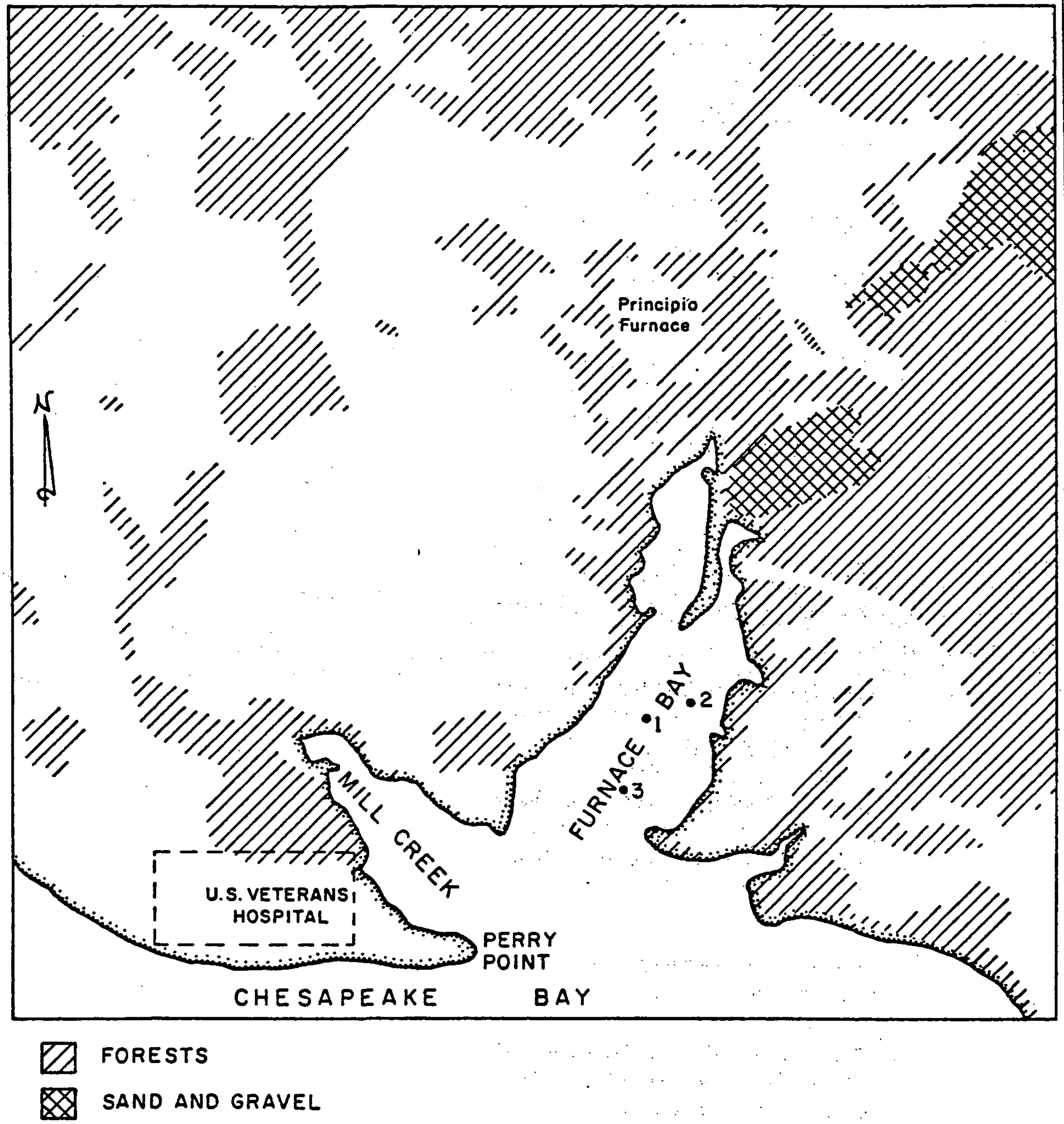


Figure 3. Locations of cores taken in Furnace Bay. Areas with dashed lines are forested and hatched areas are sand and gravel quarries.

HISTORY

In this section, we present synopses of trends and events in the Susquehanna River Basin and Furnace Bay watershed which relate directly to the stratigraphic records from Susquehanna Flats and Furnace Bay.

The Susquehanna River Basin

The Susquehanna River drains a 25,510 mi^2 basin which extends well into New York State (Figure 4). Despite its size, practically every acre of the watershed has been altered at some point in the past 3 centuries to meet demands for food, lumber, coal, residential and industrial space (Susquehanna River Basin Study Coordinating Committee 1970).

The land-use history of the watershed is extremely complicated. The task of reconstructing that history has been simplified by focusing upon major statewide trends in the lumber and anthracite coal industries. The analysis of agriculture in the watershed emphasizes those counties in the southern basin which are adjacent to the Susquehanna River (Table 1).

TABLE 1. AGRICULTURAL STATISTICS FOR SELECTED YEARS IN THE SOUTHERN SUSQUEHANNA RIVER BASIN*

	Acres of improved land†	% of total area	Acres in principal field crops‡	% of total area
1844	2,448,160	51.3	not available	----
1884§	2,958,510	61.9	1,266,010	26.5
1925	2,482,920	52.0	1,195,570	25.0
1964	2,524,812	52.9	1,161,780	24.3

* Includes Federal Census data for Harford and Cecil Counties, Maryland, plus the following counties in Pennsylvania: Chester, Cumberland, Dauphin, Juniata, Lancaster, Lebanon, Mifflin, Montour, Northumberland, Perry, Snyder, Union and York.

† Includes total cropland, pastureland, orchardland, vineyards, etc.

‡ Corn, wheat and oats.

§ Average of 1880 and 1890 census data.

We have distinguished, for purposes of this study, the following major periods and events which are described in the accompanying text.

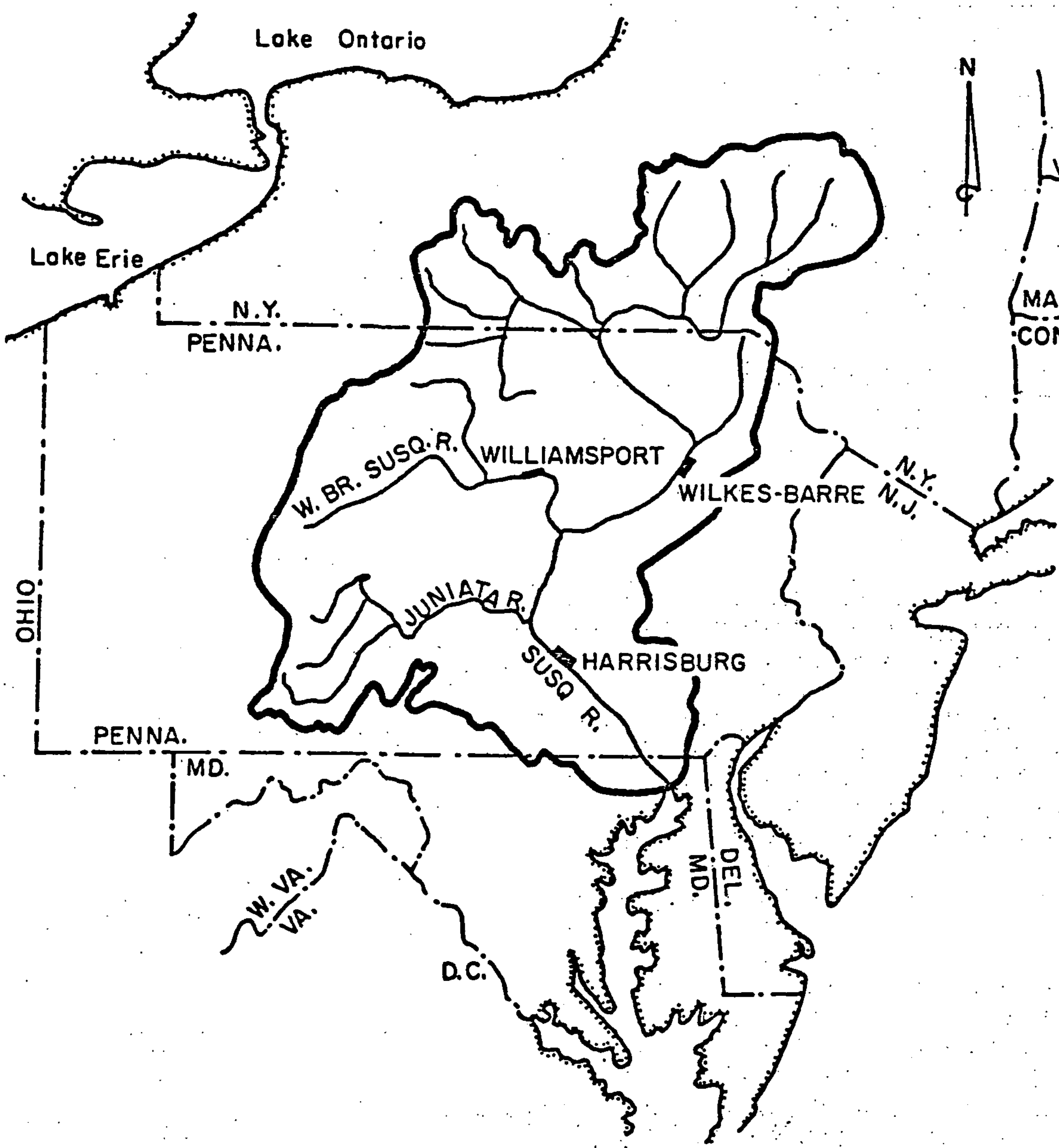


Figure 4. The Susquehanna River drainage basin.

1. The Lumber Industry:

1700-1840 - Hardwood Lumbering in the Pennsylvania Piedmont for cropland and charcoal.

1830-1860 - Peak production of white pine from West Branch and upper watershed.

1869-1900 - Peak production of eastern hemlock in upper watershed.

1910-1930 - Decline of American chestnut in eastern Pennsylvania.

2. Anthracite Industry:

1803-1850 - Development of the industry.

1875-1885 - Beginning of coal particle deposition in Upper Bay sediments.

1890-1915 - Peak production.

1920-Present - Acid mine drainage in central-eastern watershed.

3. Agriculture:

1700-1760 - European occupation of southeastern Pennsylvania.

1760-1820 - Establishment of stable agricultural system.

1790-1820 - Rise of ragweed in Upper Bay pollen record.

1870-1890 - Peak number of farms and peak crop acreage in southeastern Pennsylvania. Farm abandonment in the Upper Basin.

1950-Present - Suburbanization of river watershed with modest decrease in farmland.

4. Major Floods:

October 1786

March 1846

March 1865

June 1889

May 1894

March 1902

March 1904

March 1936

May 1946

March 1964

June 1972

The Lumber Industry--

Lumbering in the state before 1700 matched the need for cropland. Indians and pioneer settlers typically girdled trees to clear one or several acres for planting. Fires were occasionally set to drive out game and to create forage (Defebaugh 1907).

Between 1700 and 1760, an expanding population of European immigrants spread northward and westward from Philadelphia. The area into which they migrated contained mixed deciduous forests (white oak, red oak, black oak, chestnut, pignut hickory, and black walnut) interrupted by occasional stands of yellow pine and, on steeper river banks, hemlock (Lemon 1972). During this time, scattered sawmills sprang up as far west as the Susquehanna River to provide lumber for developing towns and homesteads. During this period, iron furnaces fired by hardwood charcoal consumed substantial tracts of forest outside the towns and in rural areas (Bining 1938). Nonetheless, in 1760, large tracts of open forest still characterized most of the watershed.

During the next 40 years, existing farms and towns in the southern basin expanded considerably. The valleys east of the Allegheny Mountains were settled at densities of 20 to 40 persons per mi^2 (Lemon 1972). Deforestation for cropland, charcoal and lumber continued, but it was piecemeal and thus difficult to assess.

Charcoal manufacturing declined quickly when charcoal was replaced by coal and coke (c. 1840) as the fuel for blast furnaces (Bining 1938). By the mid-19th century, much of the timberland of the Piedmont valleys and floodplains was cleared for agriculture, and upland slopes were cut for fuel and pasturage.

Softwood lumbering in the Middle and Upper Basin, especially along the West Branch of the Susquehanna, was systematic and devastatingly thorough (Tonkin 1940). Between the late 18th century, when speculators first began buying up tracts along the West Branch, and 1900, white pine and eastern hemlock were harvested faster than they could regenerate on both sides of the Allegheny Mountains. Pine production declined steadily after reaching its peak during the 1850's. Hemlock grew scarce within another 40 years but not before Pennsylvania had led the nation in lumber production for nearly two decades (Steer 1948).

The demise of Pennsylvania's forests, which can be inferred from Figure 5, is reported by the state forester in the 1880 U. S. Census:

> "Merchantable pine has now almost disappeared from the State, and the forests of hardwood have been replaced either by second growth or have been so generally culled of their best trees that comparatively little valuable hardwood timber now remains. Large and valuable growths of hemlock, however, are still standing in northwestern Pennsylvania."

The spread of the chestnut blight (*Endothia parasitica*) from an epicenter near Philadelphia was so rapid that by 1930 nearly every tree in the State was infected, and the majority of trees east of the Allegheny Mountains

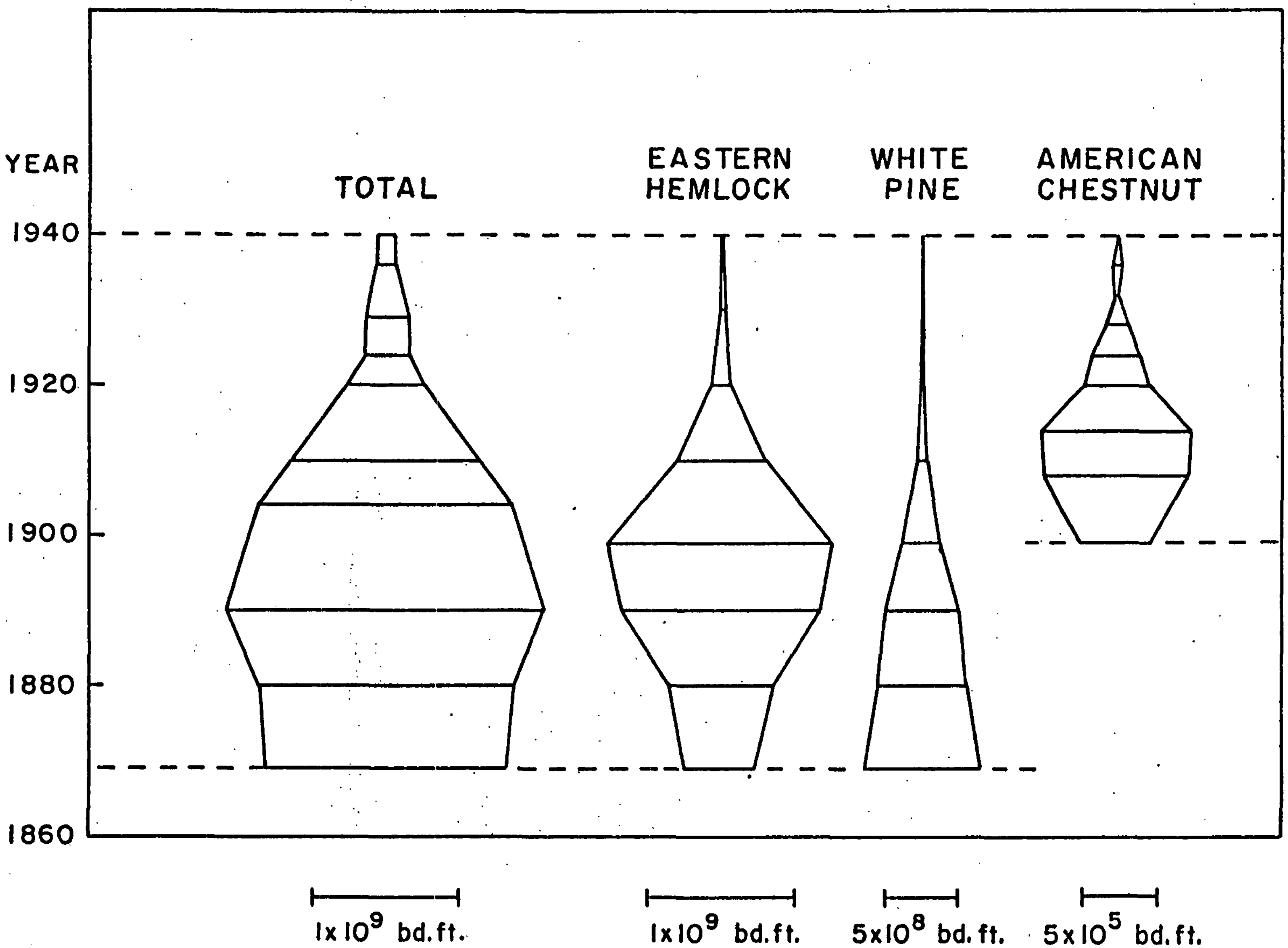


Figure 5. Reported lumber production in Pennsylvania for selected years (Steer 1948).

were dead. Infection rates of 77 percent in 1912 and 88 percent in 1913 were reported for 1,637 trees examined in the vicinity of Philadelphia (Commonwealth of Pennsylvania 1915). Because infection rates were high in the southeastern corner of Pennsylvania by 1910, it seems likely that chestnut pollen began declining at this time in the pollen assemblages of the Upper Bay and probably disappeared altogether by 1930.

The Anthracite Coal Industry--

The anthracite coal industry in Pennsylvania was centered on deposits in Lebanon, Dauphin, Schuylkill, Northumberland and Luzerne Counties--in other words, the central eastern section of the Susquehanna watershed. From its beginnings in the early 19th century to its peak and subsequent decline in the early 20th century (Table 2), coal mining had prodound effects on the culture and the landscape of this region. The urbanization of northeastern Pennsylvania accompanied anthracite output. Mining was also responsible for "acidic streams, scarred landscapes, underground fires, land subsidence, and abandoned mine buildings and breakers" (Susquehanna River Basin Study Coordinating Committee 1970).

TABLE 2. PRODUCTION OF PENNSYLVANIA ANTHRACITE FOR CERTAIN SELECTED YEARS (from Susquehanna River Basin Coordinating Committee 1970)

Year	Production (million of tons)
1825	0.04
1837	1.2
1859	10.1
1891	50.7
1917	99.6
1923	93.3
1933	49.5
1944	63.7
1960	18.8
1964	17.2

The anthracite industry is reflected in the sediments of the Upper Bay. Anthracite particles dominate some horizons in the Susquehanna Flats sediments. They began accumulating sometime in the second half of the 19th century, probably around 1880 (S. Lintner, personal communication), thus providing a dateable horizon in the sediments of the Susquehanna Flats.

Agriculture--

The earliest farms in Pennsylvania appeared over 300 years ago. It was not until the 18th century, however, that settlers spread out from the Delaware River basin and Philadelphia westward into Lancaster County. By 1760, settlers had occupied land east of the Susquehanna River at average densities of 20 to 29 persons per mi^2. The best farmlands west to Cumberland County were only slightly less populous. During the next 40 years, the occupied lands were cleared for farmland and fuel and were connected by roads and political institutions. Despite movements of persons westward towards Ohio, the population densities east of the Alleghenies doubled between 1760 and 1800 (Lemon 1972).

Benjamin Latrobe's map of the Susquehanna River, the product of a survey performed in 1801 between Columbia, Pennsylvania and Havre de Grace, Maryland, provides a general impression of the extent of farmland along the River. At that time, long reaches of river are still enclosed by dense forest, but cropland dominates other stretches, particularly along the approach to Columbia (for a summary description of the map, see Lintner, unpublished manuscript).

Apparently, enough land was cleared in the southern Susquehanna watershed in the latter 18th century to promote the rise of *Ambrosia* (ragweed) pollen in the pollen assemblage borne by the river. We have assigned rough dates of ~~1790 and 1820~~ to the ~~first appearance and rise to prominence of ragweed pollen~~ in the pollen record of the Upper Bay.

Table 1 (shown previously) shows trends in the acres of improved land in selected counties of the Susquehanna Basin since 1844 (U. S. Census 1844, 1884, 1924, 1964). These Census data suggest that the amount of improved land is roughly the same now as it was in 1844. Land in crops, orchard, pasture and other improvements (i.e., improved land) peaked during the 1880's and then declined gradually to approximately 2.5 million acres in 1920 (Johnson 1929). Seventy-five percent of the reduction between 1880 and 1920 is in orchards, vineyards and pasturelands. The number of farms and the average size of individual farms also drops appreciably during this time.

The late 19th and early 20th century was an era of widespread farm abandonment throughout the Piedmont, largely due to soil exhaustion (Trimble 1974, Craven 1926). Though there was abandonment in the upper Susquehanna watershed, the farms of the Pennsylvania Piedmont were exceptionally stable. This stability was partly due to the unusually fertile soils of the area and to its topography, as well as its proximity to major marketplaces such as Philadelphia (James 1928). Corn, wheat, oats and hay are the principal crops of the region much as they were during the early years of agriculture in southeastern Pennsylvania (Lemon 1972).

Floods--

The dates of major floods in the basin since 1784, as recorded at a gauging station at Harrisburg, Pennsylvania (70 miles from the mouth of the river), are listed on page 13. The six largest floods which have occurred at Harrisburg since 1889 are those of June 1972, March 1936, June 1889, May 1894, March 1964 and May 1946 in order of decreasing intensity.

<u>Furnace Bay Watershed</u>

The name Furnace Bay refers to a furnace built by the Principio Iron Company in 1724. This company operated one of the region's first iron works on Principio Creek between 1724 and 1787 (Bining 1938).

Some of the local historical events which might have affected the biostratigraphic record in Furnace Bay sediments are outlined below:

<u>Pre-1900</u>

1658 — George Simcoe built a small farm on the western shore of Furnace Bay. Other settlers probably established themselves on Perry Point. Certainly some forest acreage was cleared for crops (Johnston 1881).

1724 — The Principio Furnace was completed, along with a grist mill and housing for colliers and other employees. Large tracts of hardwood must have been cut for charcoal to fuel the furnace. Cropland was probably developed to provide food for company employees (Miller 1949).

1750 — Some plantation homes were established on Perry Point around this time, notably the Thomas mansion.

1750-1900 — During most of the 18th century, the principal source of income for local inhabitants was trapping and fur trading. These were generally replaced as an economic base by agriculture around the turn of the century. In particular, the western shore of Furnace Bay was continuously planted in corn, wheat, hay and other crops throughout the 19th century (County Directors of Maryland 1956).

<u>Post-1900</u>

1918 — The local population remained small and agriculturally based until 1918, when an ammonium nitrate (explosives) plant was built on Perry Point adjacent to Mill Creek. The construction included "water, sewer and stream underground conduits, streets, railroads, large machinery installations, a village of more than 300 houses and theatre" (County Directors of Maryland 1956).

In 1922, the entire complex was converted to a U.S. Veterans Hospital. Sewage from the facility, as well as from a rapidly expanding population in Perryville, was (and still is) discharged into Mill Creek, and was probably responsible for the substantial organic enrichment of Mill Creek and Furnace Bay still evident today (Upper Chesapeake Watershed Association 1970).

1952 Beginning in 1952, sand and gravel were excavated from four locations in the Furnace Bay watershed (Figure 3, page 10). One pit was situated against Principio Creek at the head of Furnace Bay.

Excavation for sand and gravel has now exposed extensive areas of the Furnace Bay watershed, and undoubtedly affects both the character of sediments and their rate of deposition into Furnace Bay.

SECTION 4

SUBMERGED AQUATIC VEGETATION (SAV)

INTRODUCTION

Extensive beds of submerged aquatic macrophytes (SAV) have been a familiar, and variously appreciated, aspect of most tributaries and shoal areas of Chesapeake Bay. Though they can be a nuisance to recreational boaters, the beds provide food and/or shelter to a wide variety of organisms, including waterfowl, fish and a host of invertebrates. Additionally, SAV communities remove some toxins from the water, stabilize sediments and dampen waves responsible for shoreline erosion (Stevenson and Confer 1978).

Research on SAV ecology and distribution in the Bay has been sporadic. Dramatic events such as the spread of water chestnut (*Trapa natans*) throughout the Potomac in the 1920's, or the decline of eelgrass (*Zostera marina*) in the southern Bay during the 1930's, have drawn attention to SAV communities. Waterfowl biologists have provided descriptions of and investigations into the grasses since the turn of the century.

Not until 1958, however, with the initiation of a SAV survey in the Susquehanna Flats (Bayley et al. 1978), has there been systematic monitoring of grass beds. Since then various investigators (Anderson 1972, Southwick and Pine 1975, Steenis et al. 1962, Stevenson and Confer 1978) have documented the explosive spread and sudden decline of Eurasian milfoil (*Myriophyllum spicatum*) throughout the Maryland tributaries during the late 1950's and early 1960's, and the startling disappearance of grass beds throughout the northern Bay in the wake of Hurricane Agnes in 1972. The post-Agnes decline of SAV beds in the Upper Bay coincided with the rapid deterioration of eelgrass beds in the Lower Bay (Orth 1976).

At present, the most extensive SAV communities occupy the tidal rivers of the central Eastern Shore. Vegetation is gradually returning to a few Western Shore rivers, notably the Severn, Gunpowder, and the Bush Rivers, but so far it is not recolonizing extensively the Susquehanna Flats, the Elk, Bohemian or Sassafras Rivers. SAV is conspicuously absent from the Patuxent River and most of the Potomac River. In Virginia, eelgrass beds remain greatly reduced compared to 1971, but there have been no significant declines in the past 2 years.

The recent record suggests that SAV communities are unpredictable and prone to large swings in abundance and in species composition.

Our 1-year feasibility study grew out of a desire to know more about the broad history of SAV populations in different tributaries of Chesapeake Bay.

It was felt that such information would complement ongoing ecological studies in providing perspective on the behavior of grass beds over the course of decades and centuries, rather than months or years. Biostratigraphic techniques have been explored to provide answers to questions such as: What were the SAV communities like in the pre-colonial Bay ecosystem? How has SAV varied in response to massive watershed disturbances--lumbering, agriculture, etc.--of the past 3 centuries? Is the current decline in SAV anomalous or has it occurred before in the Bay? Are population fluctuations cyclical?

In order to address these questions, an attempt was made this year to determine (1) the parts of SAV that are best preserved in the sediment and that are most readily identifiable and whether or not there is selective preservation, and (2) the amount of variability in the spatial distribution of the seeds in the sediments.

THE SAV FOSSIL RECORD

The biostratigraphic record of SAV in Bay sediments includes pollen, leaf and rhizome tissue and seeds. Depending upon their state of preservation, the leaves of *Elodea canadensis*, *Vallisneria americana*, *Myriophyllum spicatum*, *Zostera marina*, *Potamogeton perfoliatus*, *P. crispus* and *Ceratophyllum demersum* may be identifiable. Leaves of the genus *Najas* are also recognizable. Unfortunately, leaves are often fragmented beyond recognition, and they are difficult to quantify. Nonetheless, leaves present a record of presence or absence which may provide the best available information for some species.

Seed and pollen production of major SAV species is summarized in Table 3. Note that only five species produce pollen with a persistent exine. Members of the genus *Potamogeton* and *Myriophyllum spicatum* produce aerial flowers and the pollen is wind-dispersed. Pollen of *Elodea canadensis* and *Vallisneria americana* is released at the water surface and distributed locally. None of the SAV species produce enough pollen to figure significantly in the pollen assemblage, although pollen grains of *Myriophyllum* and *Potamogeton* appear consistently in some of the cores analyzed.

Seeds provide the most consistent information on the historical distribution of SAV communities, and they tend to be well preserved in most sediments. Fragments are recognizable to genus and usually to species. However, seed profiles in the sediment are not easily interpreted. As underlined by Watts (1967), species are differentially represented in the fossil record so that the prolific seed producers and those whose seeds are well preserved are overrepresented compared to those species which produce few seeds or do not preserve well. There is variation in the distance over which different seeds are transported and in the palatability of different species to waterfowl, fish and invertebrates. Finally, the ecology of a macrofossil community must be known in order to draw meaningful inferences from the fossil record.

TABLE 3. SAV SEEDS AND POLLEN IN THE BIOSTRATIGRAPHIC RECORD

	Salinity range:(ppt)	Pollination	Pollen with persistent exine	Representation in seed record
Zostera marina	10 - 35	hydrophily	-	?
Potamogeton pectinatus	0 - 8	anemophily	+	poor
Potamogeton perfoliatus	2 - 25	anemophily	+	poor
Ruppia maritima	5 - 35	ephydrophily	-	good
Zannichellia palustris	0 - 8	hydrophily	-	good
Najas qualalupensis	0 - 10	hydrophily	-	good
Najas flexilis	0 - 10	hydrophily	-	good
Elodea canadensis	0 - 10	ephydrophily	+	poor
Vallisneria americana	0 - 1	ephydrophily	+	good
Myriophyllum spicatum	0 - 20	anemophily	+	poor

An example of SAV fossil assemblage is shown in Figure 6. The core is from Furnace Bay. Five species occur in the profile. The assemblage suggests that:

1. None of the species provide consistent records of seeds, pollen and leaf tissue.

2. *Myriophyllum spicatum* and *Vallisneria americana* show good agreement between seed and tissue presence, while *Najas spp.*, *Potamogeton spp.* (in this case predominantly *P. gramineus*) and *Elodea canadensis* show a poor correlation.

3. Of the four genera, *Potamogeton* is most poorly represented in the seed record. This is probably due to poor preservation or the exceptional palatibility of *Potamogeton* seeds to waterfowl and not to low seed production (Stark 1971). Leaf fragments are the best markers of former beds of this genus.

4. Pollen is not a useful parameter in the SAV record, since the species represented are anemophilous, making it difficult to identify the location of former beds. Also, the pollen records show poor agreement with seed and leaf records.

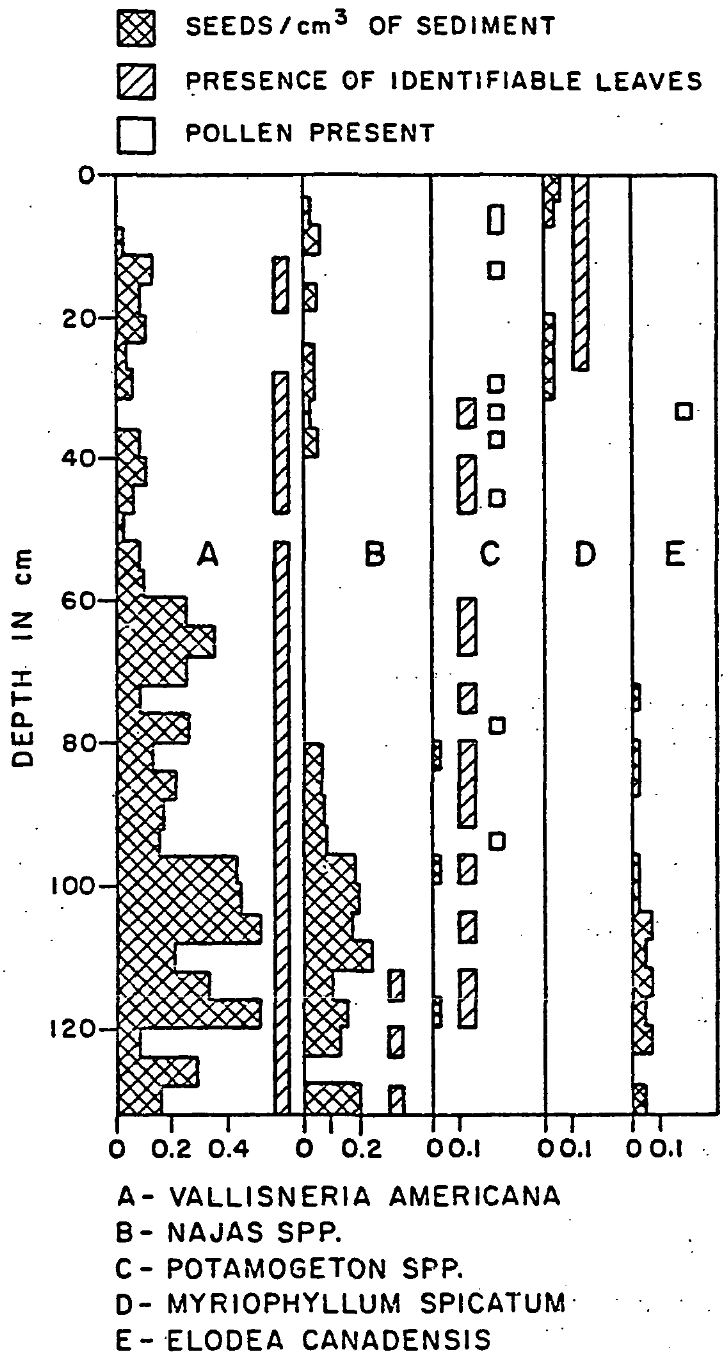


Figure 6. An example of the SAV fossil record (Core FB-II from Furnace Bay).

5. For most species, seeds afford the best fossil parameter for studying the past history of SAV.

DISTRIBUTIONS OF SEEDS IN SEDIMENTS

In order to interpret the occurrence of seeds in the sedimentary record, the decision was made to investigate the distribution of seeds in surface sediments and to try to relate the seed populations to populations of SAV in existing beds.

SAV reproduce asexually by rhizomes, turions, tubers and in many genera (e.g., *Myriophyllum* and *Elodea*) by any fragment of the plant axis bearing a dormant lateral bud (Sculthorpe 1967). Typically, senescent plants fragmentize at the end of the growing season and drift in rafts that may accumulate against the shore. Seeds may travel and settle with such rafts, or they can become detached to be moved by waterfowl, wind and water currents (Stevenson and Confer 1978, Sculthorpe 1967). The unique productivity, palatability and dispersal mechanisms of the seeds of each SAV species suggest that it may be difficult to make many generalizations about the transport of seeds. However, empirical evidence from this study, described below, as well as that of Stark (1971), Birks (1972), Praeger (1913), and Ridley (1930) suggest that seeds of many SAV species do not travel far from the parent bed.

Area of Study

Leeds Creek is a tidal tributary of the Miles River (Figure 7). It is approximately 5 km long and its width decreases from about 500 m near the mouth to 125 m near the head. A channel running up the center of the creek rises from a depth of 4.5 m near the mouth to 2.4 m just south of the Tunis Mills Bridge.

The SAV of Leeds Creek has been surveyed during the summers of 1976, 1977 and 1978 by the Youth Conservation Corps in collaboration with the Chesapeake Bay Foundation (Fenwick, unpublished manuscript). Additionally, an aerial survey outlined the location of SAV beds during the 1978 growing season (Figure 7) (Anderson et al., in press).

Since 1976, the distribution and composition of SAV communities in Leeds Creek have remained relatively stable compared to other SAV communities in the area.*

Leeds Creek was chosen for a study of the dispersal and deposition of the seeds of a few SAV species because of the work described above. In March 1979, surface sediments were collected from 77 locations along nine transects inside the creek and from three locations just outside the creek (Figure 7). The spatial distribution of seeds was compared to the distribution of SAV beds in the previous growing season to see how far seeds of different species were transported and whether they were concentrated at certain water depths. The

*Fenwick, G. 1979. Personal communication.

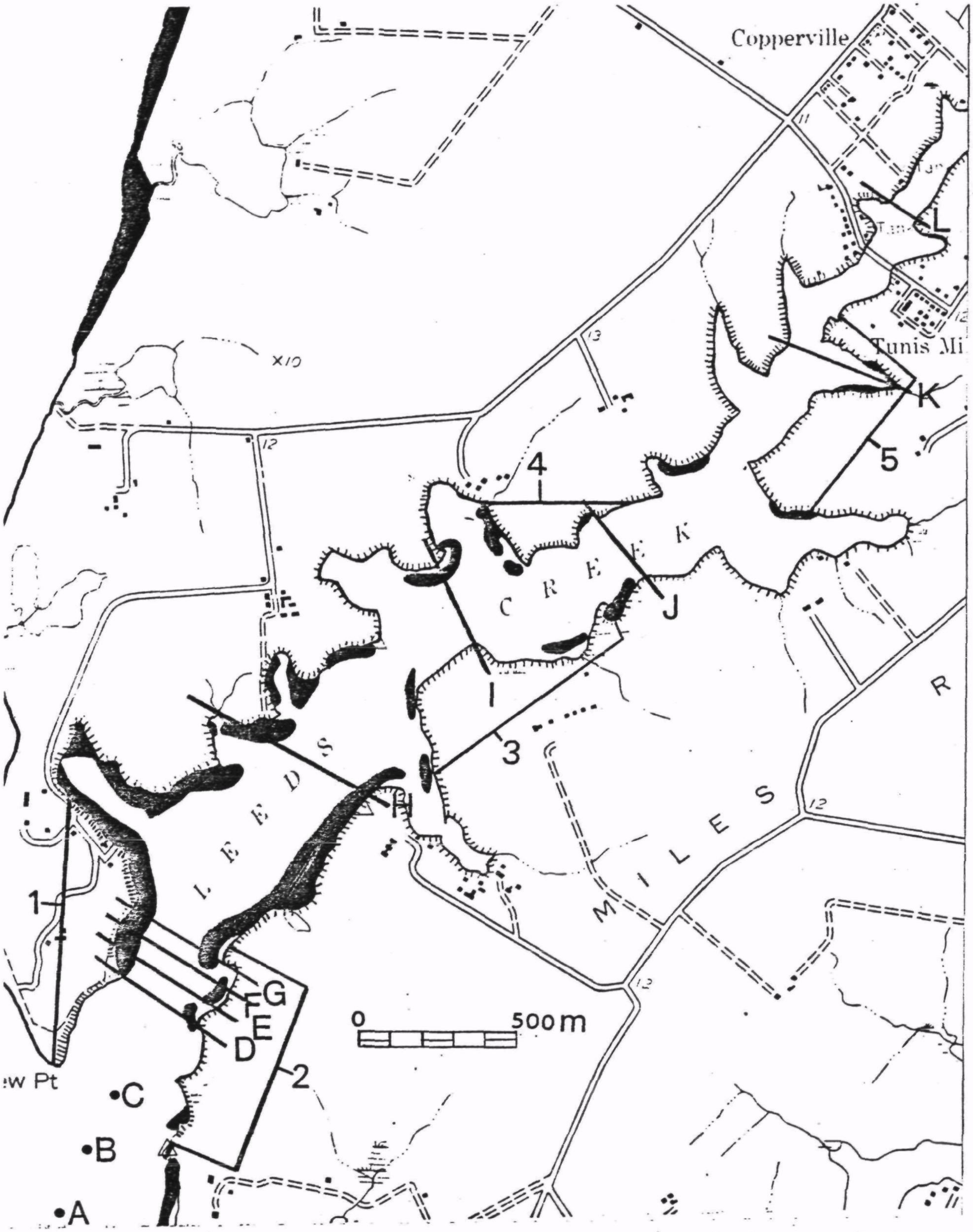


Figure 7. Locations of surface sediment transects in Leeds Creek. Black areas represent locations of SAV beds in 1978 outlined by aerial photography (Anderson, in press). Bracketed numbered areas denote areas sampled for SAV in 1978.

1978 ground cover estimates for each SAV species were checked also against seed data to see how the different species were represented in the sedimentary seed record.

The results of the study are used in interpreting SAV biostratigraphic profiles and in designing future studies.

Methods

The surface samples were collected with a piston corer 5.4 cm in diameter that was designed for this project. A short core was drawn from which all but the upper 28 cm^3 (± 3 cm^3) were discarded. Samples were stored in plastic bags and refrigerated as soon as possible.

The methodology for seed extraction and enumeration has been described in detail in the EPA Quality Assurance Report for this project.

Samples were located by transect and water depth (Figure 7). At locations A, B and C paired samples on a line from the creek channel into the Miles River were taken. Along transects D through G, samples were collected under 0.6, 1.2, 1.8 and 2.4 m of water as well as in the deepest part of the channel (approximately the center of the creek). These four transects were separated by 122 m in an area that had extensive SAV beds the previous summer. Along transects H through L samples were collected from 0.6, 1.2, and 1.8 m water depths as well as in the center of the creek.

Results

Seed data for *Zannichellia palustris*, *Ruppia maritima* and *Potamogeton pectinatus* are illustrated in Figures 8, 9, and 10. Table 4 lists the sample data in seeds/cm^3 of sediment for each species.

Homogeneity of Seed Distributions--

Data for *Zannichellia palustris* and *Ruppia maritima* are used separately to test two hypotheses: (1) seed concentrations do not vary between water depths, and (2) seed concentrations do not vary between transects. *Potamogeton pectinatus* is not included in the analysis because 68 percent of the samples do not contain *Potamogeton* seeds.

Seed concentrations are strikingly low in the channel sediments. *Zannichellia* seeds occur in 58 out of 60 (97 percent) of the nonchannel samples and in 8 out of 20 (40 percent) of the channel samples. *Ruppia* seeds are present in 58 out of 60 (88 percent) of the nonchannel samples and 3 out of 20 (15 percent) of the channel samples.

The Kruskal-Wallis nonparametric test (Hollander and Wolfe 1973) was used to determine whether the seed concentrations of the seven populations from the sediments at 0.6 m, 1.2 m, and 1.8 m water depths on both sides of the creek and from channel sediments vary with depth of water.

The Kruskal-Wallis test is similar to a rank-sum test for more than two populations. It tests the probability, in this case, that the seed data are

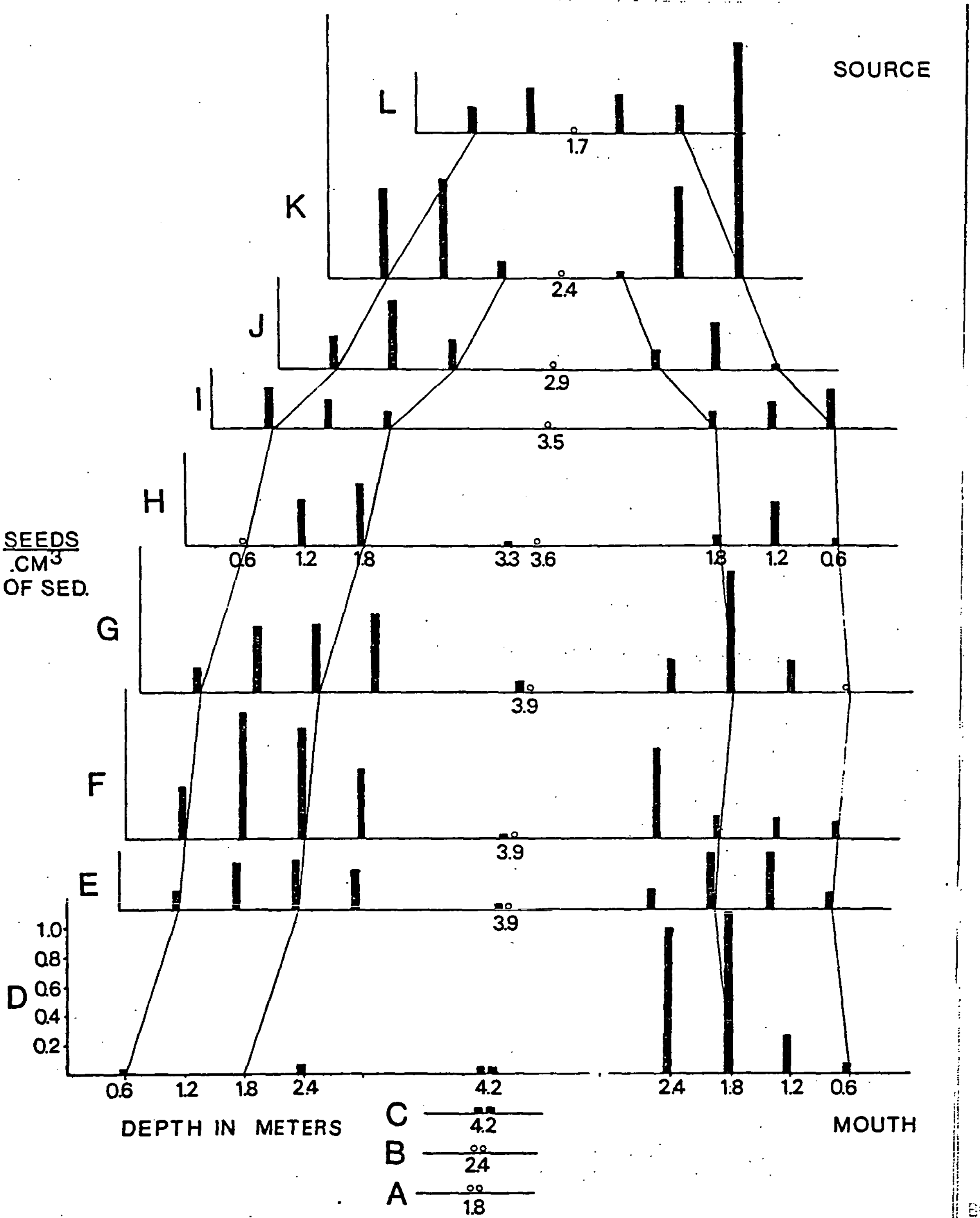
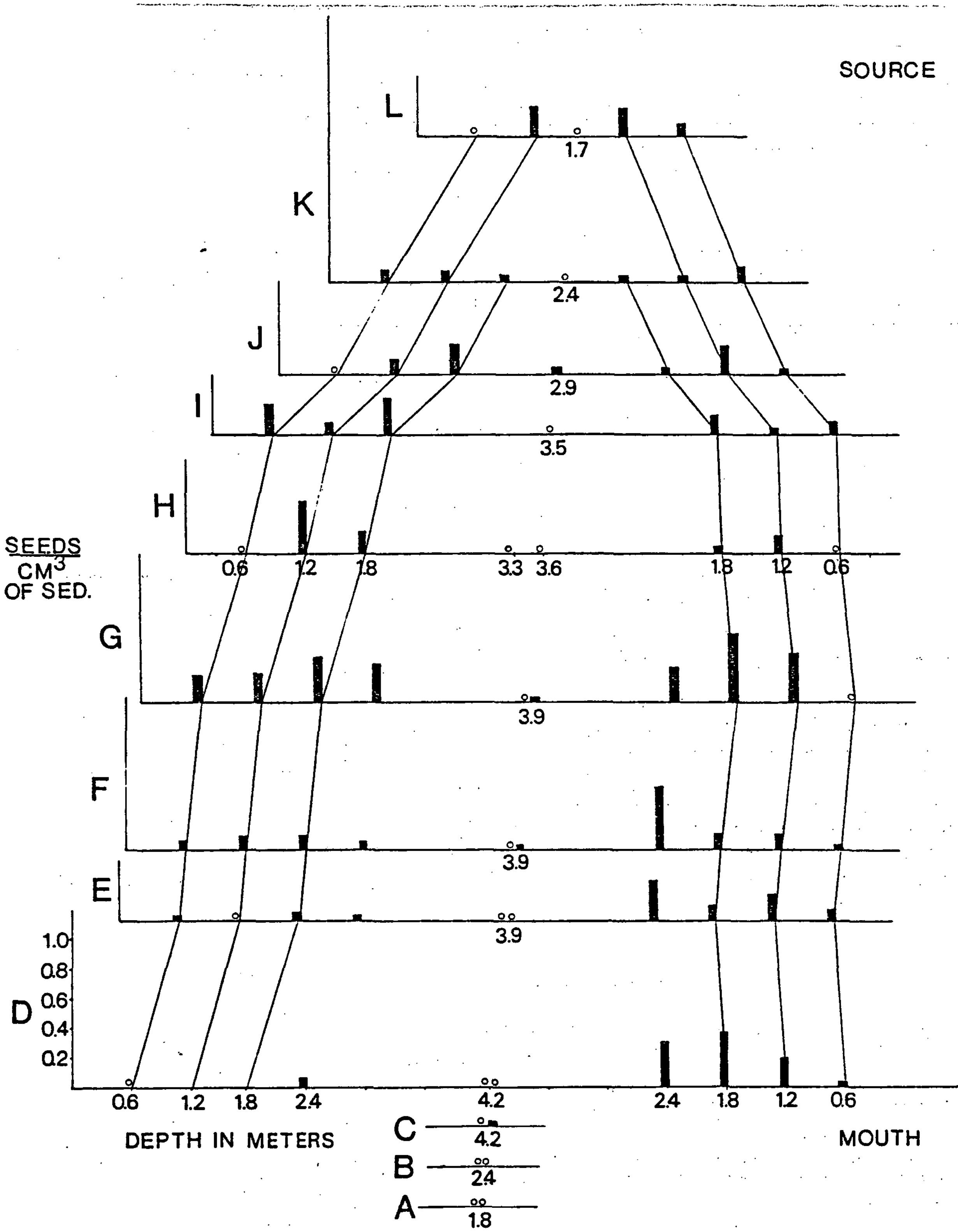


Figure 8. Seed concentrations of *Zanichellia palustris* in surface sediments of Leeds Creek.



BEGIN LAST LINE OF TEXT

Figure 9. Seed concentrations of *Ruppia maritima* in surface sediments of Leeds Creek.

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

EPA-287 (Cin.)
(4-78)

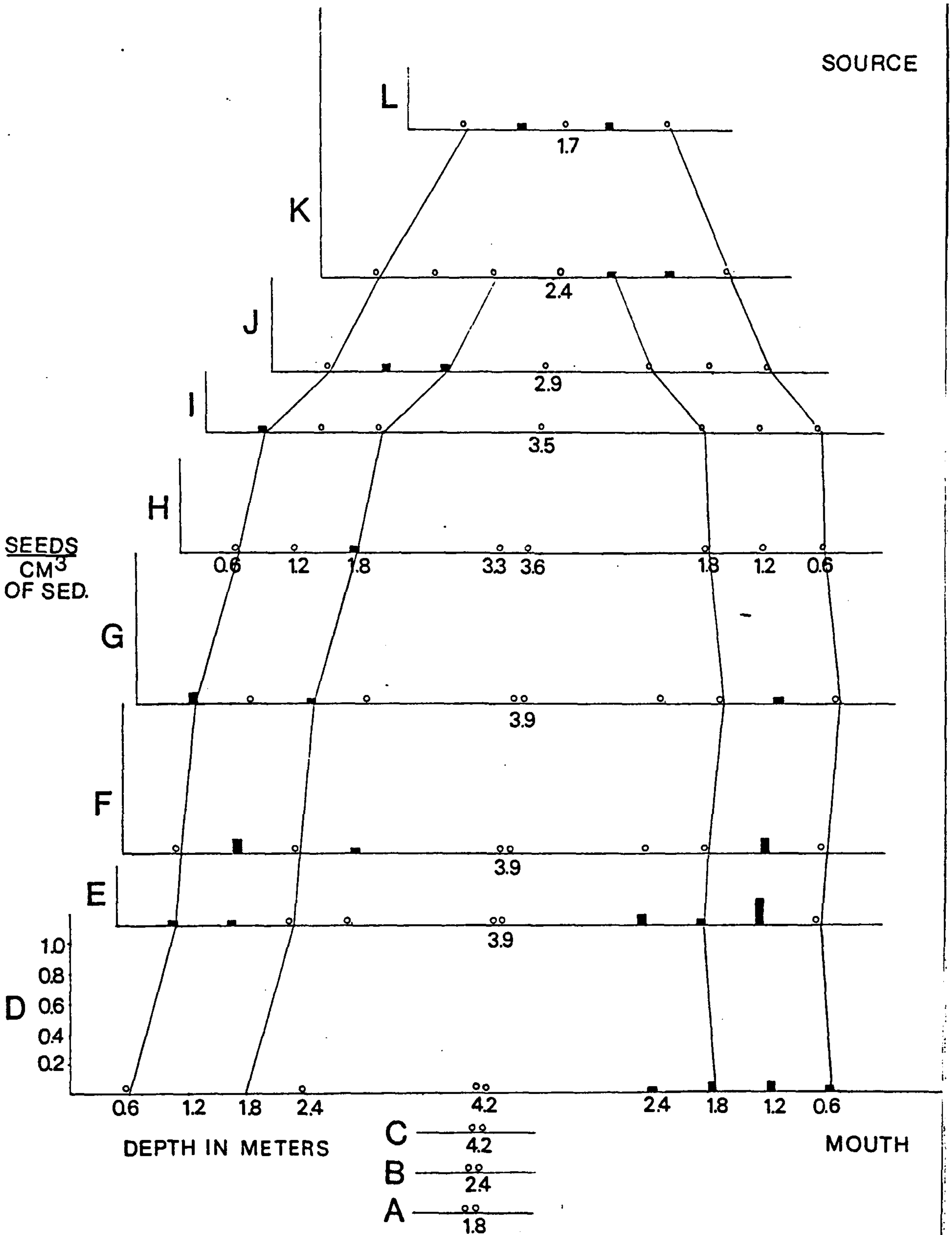


Figure 10. Seed concentrations of *Potamogeton pectinatus* in surface sediments of Leeds Creek.

TABLE 4. SAV SEED CONCENTRATIONS IN LEEDS CREEK SURFACE SEDIMENTS

Species	Transect	C_1	C_2	Seeds/cm³ at water depths sampled: West side of creek 0.6 m	West 1.2 m	West 1.8 m	West 2.4 m	East side of creek 2.4 m	East 1.8 m	East 1.2 m	East 0.6 m
Zannichellia palustris	A	0.00	0.00								
	B	0.00	0.00								
	C	0.03	0.03								
	D	0.06	0.06	0.04	0.47*	0.34*	0.06	1.0	1.12	0.26	0.07
	E	0.03	0.00	0.13	0.32	0.33	0.27	0.13	0.37	0.37	0.11
	F	0.03	0.00	0.36	0.86	0.76	0.28	0.62	0.16	0.13	0.11
	G	0.08	0.00	0.17	0.45	0.47	0.54	0.23	0.83	0.22	0.00
	H	0.03	0.00	0.00	0.31	0.41			0.07	0.29	0.04
	I	0.00		0.28	0.20	0.12			0.12	0.18	0.27
	J	0.00		0.23	0.46	0.20			0.13	0.32	0.04
	K	0.00		0.60	0.66	0.11			0.04	0.64	1.70
	L	0.00		0.17	0.30					0.35	0.17
Ruppia maritima	A	0.00	0.03								
	B	0.00	0.00								
	C	0.00	0.00								
	D	0.00	0.00	0.00	0.00*	0.24*	0.07	0.30	0.39	0.19	0.04
	E	0.00	0.00	0.03	0.00	0.06	0.03	0.27	0.10	0.17	0.07
	F	0.00	0.03	0.07	0.10	0.10	0.06	0.42	0.10	0.10	0.04
	G	0.00	0.00	0.17	0.19	0.33	0.25	0.23	0.47	0.32	0.00
	H	0.00	0.00	0.00	0.34	0.14			0.04	0.13	0.04
	I	0.00		0.20	0.08	0.24			0.12	0.04	0.08
	J	0.03		0.00	0.09	0.20			0.03	0.18	0.04
	K	0.00		0.07	0.07	0.04			0.04	0.03	0.12
	L	0.00		0.00	0.19					0.18	0.08
Potamogeton pectinatus	A	0.00	0.00								
	B	0.00	0.00								
	C	0.00	0.00								
	D	0.00	0.00	0.00	0.05*	0.02*	0.03	0.00	0.07	0.07	0.04
	E	0.00	0.00	0.03	0.03	0.00	0.00	0.07	0.03	0.17	0.00
	F	0.00	0.00	0.00	0.10	0.00	0.03	0.00	0.00	0.10	0.00
	G	0.00	0.00	0.07	0.00	0.03	0.00	0.00	0.00	0.03	0.00
	H	0.00		0.00	0.00	0.04			0.00	0.00	0.00
	I	0.00		0.04	0.00	0.00			0.00	0.00	0.00
	J	0.00		0.00	0.05	0.04			0.00	0.00	0.00
	K	0.00		0.00	0.00	0.00			0.04	0.030	0.00
	L	0.00		0.00	0.04					0.04	0.00

* Actual depths greater than 1.2 m and 1.8 m due to steep-sided sand bar.

derived from the same population using a statistic that is chi-square distributed.

Based upon this test, the hypothesis is rejected that seed concentrations at 0.6 m, 1.2 m, 1.8 m and channel depths and at 0.6 m, 1.2 m and 1.8 m depths are derived from the same population. The hypothesis is accepted that seed concentrations at 1.2 m and 1.8 m are derived from the same population (Table 5).

Results of the test are the same for seed concentrations of both *Ruppia* and *Zannichellia*.

In order to test the second hypothesis that seed concentrations at all transects are derived from the same population, transects D through K including data from 0.6 m, 1.2 m, 1.8 m and channel depths were compared again using the Kruskal-Wallis test. The hypothesis is accepted for both *Zannichellia* and *Ruppia*, although not as strongly for *Ruppia* (Table 5).

The test results for the first hypothesis indicate that seeds are deposited more consistently in sediments between 1 and 2 m of water than at 0.6 m, where there is a lot of variability in concentrations, or in the channel where they are virtually absent. Their absence in the channel suggests that the seeds are not transported far in a lateral direction from their source because the channel is the farthest location from the parent beds.

The results of the test for the second hypothesis, that seeds from all transects are from the same population, suggest that either the plants are uniformly distributed along the creek, thus producing uniform seed distributions, or that the seed distributions were homogenized longitudinally by transport process. The distribution of plants for 1977-1978 is not sufficiently detailed to indicate how uniformly the beds were distributed. Aerial photographs and field data from 1978 indicate that the parent beds may have been patchily distributed with denser beds below transect J, suggesting that longitudinal transport mechanisms are responsible for the similarity of seed populations between transects. The presence of seeds at transect L, where no vegetation was mapped in 1978, supports this expectation.

The data from transects D through G were used to calculate the number of samples needed to estimate (± 10 percent) the mean seed concentration in surface sediments of that area at three different levels of confidence for each species (Table 6). This is one way of examining the amount of variability in seed concentrations among the samples from a small area of the creek. The large sample sizes recommended by the test emphasize the degree of scatter in the data. Sampling only at 1.2 m and 1.8 m depths, where the seeds are deposited more consistently, reduces the necessary sample size, but still many samples are required.

If the spatial variability in seed flux is the same roughly from year-to-year, then there is little chance of obtaining quantitative trends in SAV populations by observing seed concentrations in only a few cores. Spatial variability in seed flux could obliterate any temporal trends in SAV populations. On the other hand, the samples are sufficiently similar in the presence and

TABLE 5. ANALYSIS OF LEEDS CREEK SAV SEED CONCENTRATIONS USING KRUSKAL-WALLIS NONPARAMETRIC TEST (HOLLANDER AND WOLFE 1973)

	Hypothesis	Species	Sample	Result
1.	Seed concentrations do not vary between depths.	*Zannichellia palustris*	Transects D-K 0.6 m, 1.2 m, 1.8 m, and channel	reject ($p < 0.01$)
			Transects D-K 0.6 m, 1.2 m, 1.8 m	reject ($p < 0.01$)
			Transects D-K 1.2 m, 1.8 m	accept ($p = 0.30$)
		Ruppia maritima	Transects D-K 0.6 m, 1.2 m, 1.8 m, and channel	reject ($p < 0.01$)
			Transects D-K 0.6 m, 1.2 m, 1.8 m	reject ($p < 0.01$)
			Transects D-K 1.2 m, 1.8 m	accept ($p = 0.20$)
2.	Seed concentrations do not vary between transects.	*Zannichellia palustris*	Transects D-K 0.6 m, 1.2 m, 1.8 m, and channel	accept ($p = 0.80$)
		Ruppia maritima	Transects D-K 0.6 m, 1.2 m, 1.8 m, and channel	accept ($p = 0.70$)

absence of major SAV species, especially samples from 1.2 m and 1.8 m, that presence-absence records of dominant SAV species in Leeds Creek could be assembled from a much smaller number of samples.

TABLE 6. NUMBER OF SAMPLES REQUIRED TO BE 80, 90, and 95 PERCENT CONFIDENT OF ESTIMATING (WITHIN 10 PERCENT) MEAN SAV SEED CONCENTRATIONS IN TRANSECTS D-G (SNEDECOR AND COCHRAN 1976)

Plant species	Water depths included in mean	Mean seeds/cm^3	Variance	Level of confidence (%)	No. of samples necessary
Zannichellia	0.6 - 1.8 m + channel	0.309	0.079	95	331
Zannichellia	0.6 - 1.8 m + channel	0.309	0.079	90	223
Zannichellia	0.6 - 1.8 m + channel	0.309	0.079	80	138
Zannichellia	1.2 - 1.8 m	0.466	0.074	95	137
Zannichellia	1.2 - 1.8 m	0.466	0.074	90	92
Zannichellia	1.2 - 1.8 m	0.466	0.074	80	57
Ruppia	0.6 - 1.8 m + channel	0.139	0.025	95	518
Ruppia	0.6 - 1.8 m + channel	0.139	0.025	90	348
Ruppia	0.6 - 1.8 m + channel	0.139	0.025	80	215
Ruppia	1.2 - 1.8 m	0.215	0.029	95	251
Ruppia	1.2 - 1.8 m	0.215	0.029	90	169
Ruppia	1.2 - 1.8 m	0.215	0.029	80	105
Potamogeton	0.6 - 1.8 m + channel	0.037	0.005	95	1461
Potamogeton	0.6 - 1.8 m + channel	0.037	0.005	90	983
Potamogeton	0.6 - 1.8 m + channel	0.037	0.005	80	608
Potamogeton	1.2 - 1.8 m	0.056	0.007	95	893
Potamogeton	1.2 - 1.8 m	0.056	0.007	90	600
Potamogeton	1.2 - 1.8 m	0.056	0.007	80	372

Comparisons of Seed Distributions in Surface Sediments with the 1978 Vegetation Survey--

The results of 1978 field sampling at five locations (Figure 7) in Leeds Creek are summarized in Table 7 (Fenwick and Maldeis, manuscript in preparation). Five SAV species are recorded in Leeds Creek in 1978. Three of the five species are present in the seed record. These three species (*Ruppia maritima*, *Zannichellia palustris* and *Potamogeton pectinatus*) account for 98.9 percent of the ground cover (as visually estimated) in the areas sampled in 1978. Data in Table 7 suggest that *Zannichellia* is overrepresented in the seed record (compared to *Ruppia*) since *Zannichellia* seeds occur in consistently higher concentrations than *Ruppia* seeds, despite 87.3 percent ground coverage by *Ruppia* and only 8.5 percent by *Zannichellia*. The 1978 ground cover data may underestimate the extent of *Zannichellia* in the creek since they were collected in July, and *Zannichellia* populations often decline by late June (Stevenson and Confer 1978). Additionally, *Zannichellia* beds may have a higher seed output than *Ruppia* beds, or the seeds may suffer less predation by waterfowl and other organisms than *Ruppia* seeds. Both species preserve well in the sediments.

TABLE 7. RESULTS OF THE 1978 LEEDS CREEK SAV SURVEY (FENWICK AND MALDEIS, MANUSCRIPT IN PREPARATION).

Area	Stations (n)	Stations with Vegetation (%)	Ground Cover *Ruppia maritima*	Ground Cover *Zannichellia palustris*	Ground Cover *Potamogeton pectinatus*	Ground Cover *Elodea canadensis*	Ground Cover *Potamogeton perfoliatus*
1	38	58	83.9	11.8	----	4.1	0.2
2	48	83	72.4	12.0	15.6	----	----
3	57	79	95.6	3.3	----	1.1	----
4	28	79	85.3	14.7	----	----	----
5	32	50	99.1	0.9	----	----	----
	Average:	69.8	87.3	8.5	3.1	1.0	< 0.1

Potamogeton perfoliatus and *Elodea canadensis* are minor components of the 1978 plant community. They do not appear in the seed record of the surface sediments.

Because *Ruppia* and *Zannichellia* beds were scattered through the creek, it was difficult to estimate the distances over which their seeds might have been transported by water currents. Seeds did occur in appreciable numbers 250 m upstream from the nearest reported beds. *Potamogeton pectinatus* seeds occurred as far as 3.5 km from the beds at the mouth of the creek, though the majority of seeds occurred along the four transects (D-G) in proximity to where the species was growing in 1978. Waterfowl may have played a role in the broad dispersal of *Potamogeton* seeds.

CONCLUSIONS

Distributions of SAV seeds are highly variable in surface sediments but seed concentrations are higher and less variable in sediments where the water is from 1.2 to 1.8 m deep. The distributions are not unexpected in view of the fact that distributions of SAV species are extremely patchy and the size of the seeds (disregarding floating mechanisms) determines that they are not likely to be transported any great distance by estuarine processes. The variability that is characteristic of these distributions suggests that data from a large number of cores would be necessary to obtain comparative quantitative data with any significant degree of confidence. However, major trends in dominant vegetation can be observed by comparing the presence/absence of seeds of most species from only a few cores.

SAV BIOSTRATIGRAPHY OF UPPER CHESAPEAKE BAY

The Susquehanna Flats was chosen as a site for a study of SAV biostratigraphy because the area has had a diverse and extensive SAV community, in the past. Also, since 1958, the vegetation has been sampled along 37 km of transects by scientists from the Migratory Bird Habitat and Research Laboratory (MBHRL). The results of this survey are summarized by Bayley et al. (1978).

Three cores from the Susquehanna Flats and four cores from Furnace Bay were analyzed for SAV seeds. Our objectives were: (1) to see how variable the seed record is between cores within each area, (2) to compare the SAV records of two areas closely related spatially but different hydrodynamically, (3) to test the SAV record of recent sediments against the distribution of SAV beds during those years as established by the MBHRL Survey, and (4) generally, to gain some measure of the resolving power of the biostratigraphic approach as applied to SAV populations while examining trends in SAV populations of the Upper Chesapeake Bay before and after European settlement.

The Susquehanna Flats

Core locations in the Susquehanna Flats are in the vicintiy of the MBHRL sampling transect which ran between Havre de Grace and Spesutie Island (see Figure 2). It was hoped that the locations would be far enough south of the Susquehanna River so sediments would be free from periodic scouring, as implied by the U. S. Army Corps of Engineers (1975). Using a piston corer 5.42 cm in diameter two cores from site 1, two from site 2, and one from site 3 were collected (Figure 2). One core from each site has been analyzed (Figure 11).

The methodology for seed extraction and enumeration is provided in the EPA Quality Assurance Report. Results are plotted as seeds per cm^3 of sediment in Figures 12 through 16.

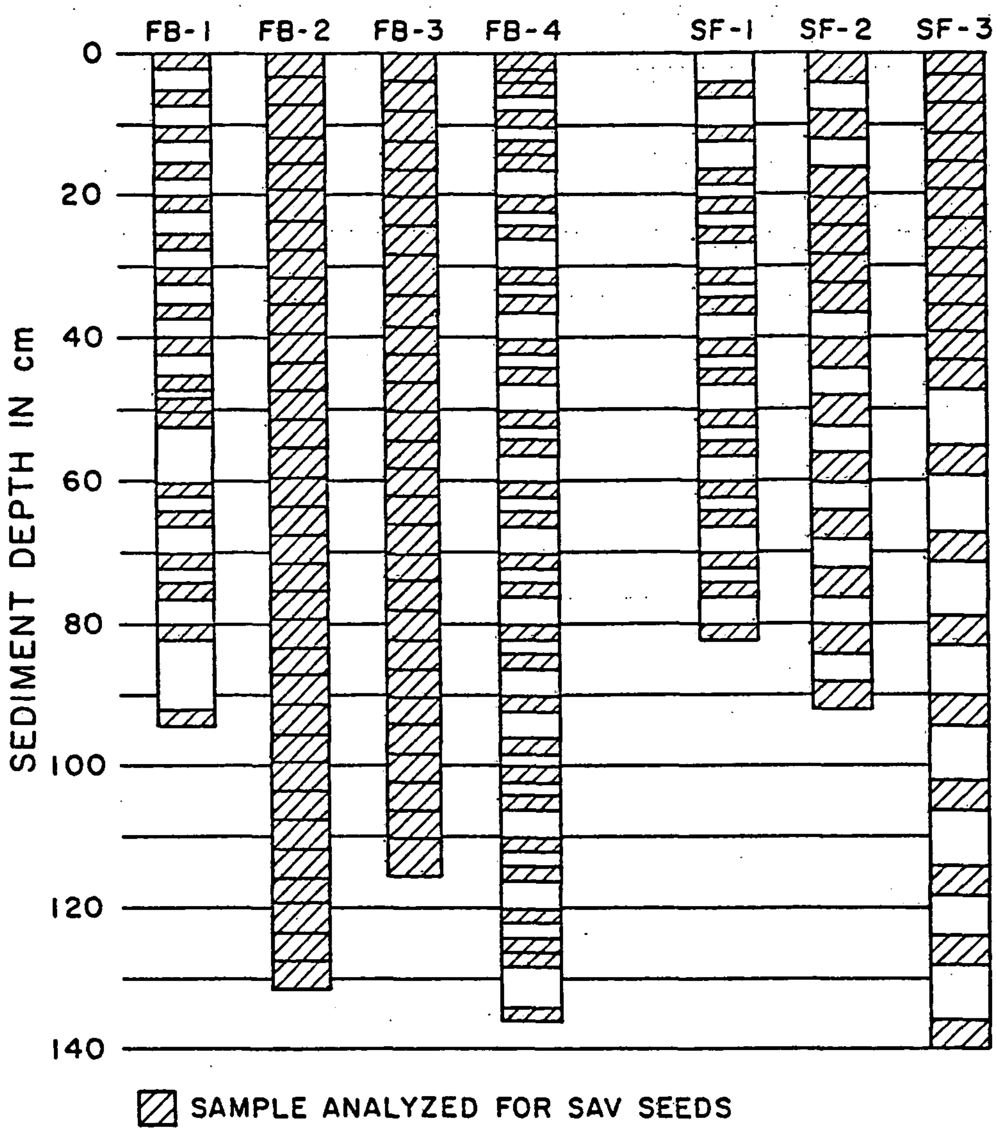


Figure 11. Upper Chesapeake Bay cores showing levels analyzed for SAV seeds.

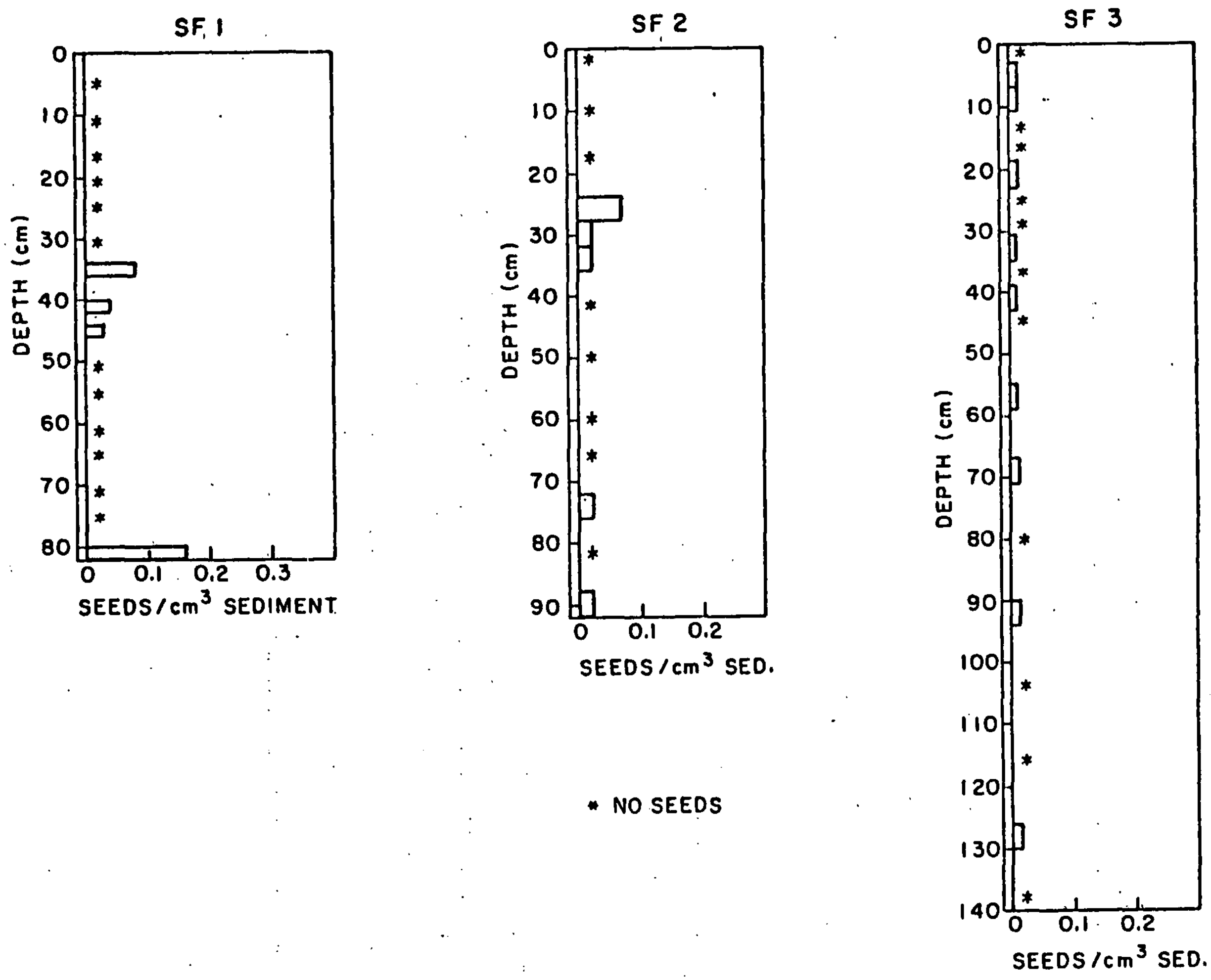


Figure 12. Seed concentrations of *Vallisneria americana* in cores from Susquehanna Flats.

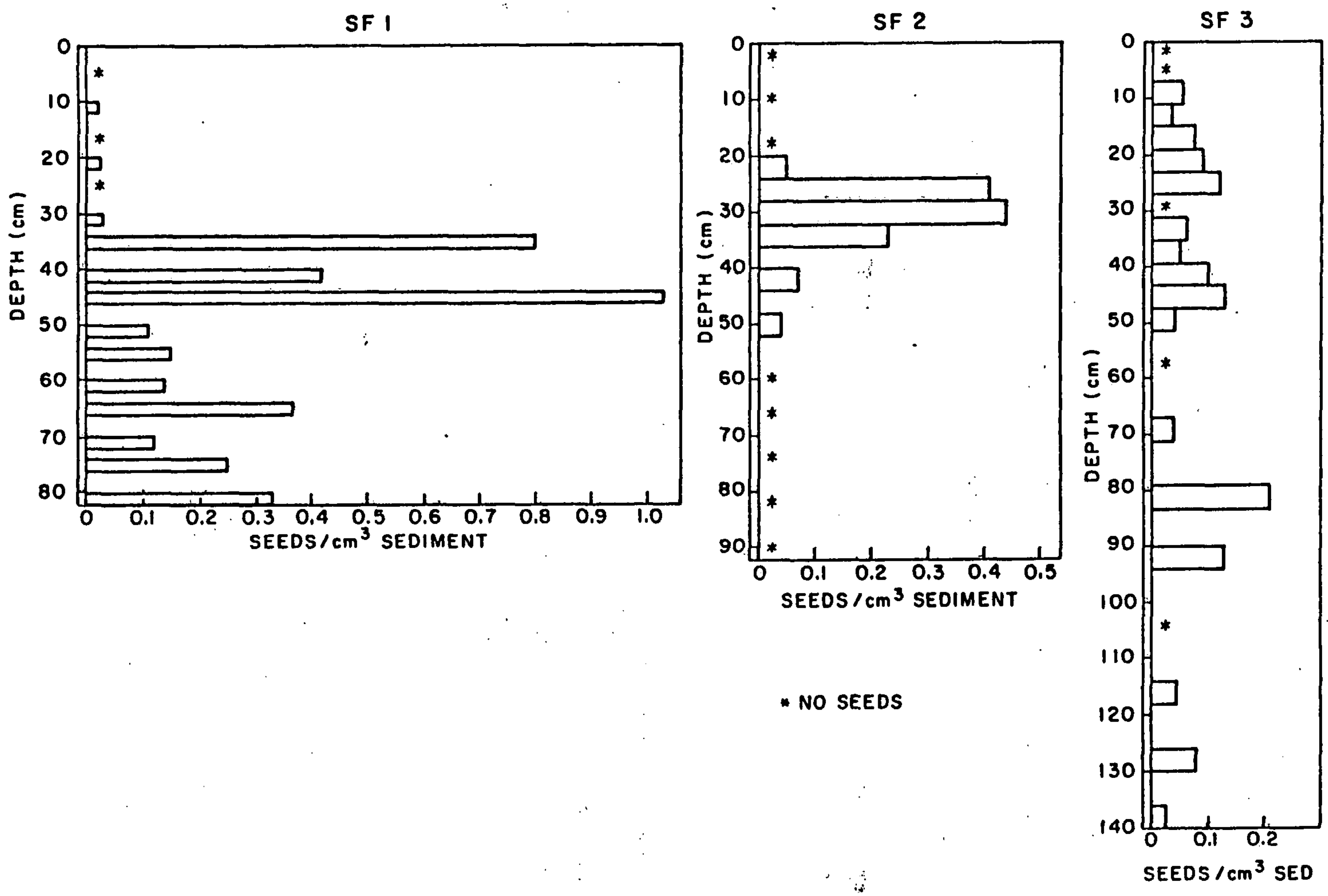


Figure 13. Seed concentrations of *Najas flexilis* in cores from Susquehanna Flats.

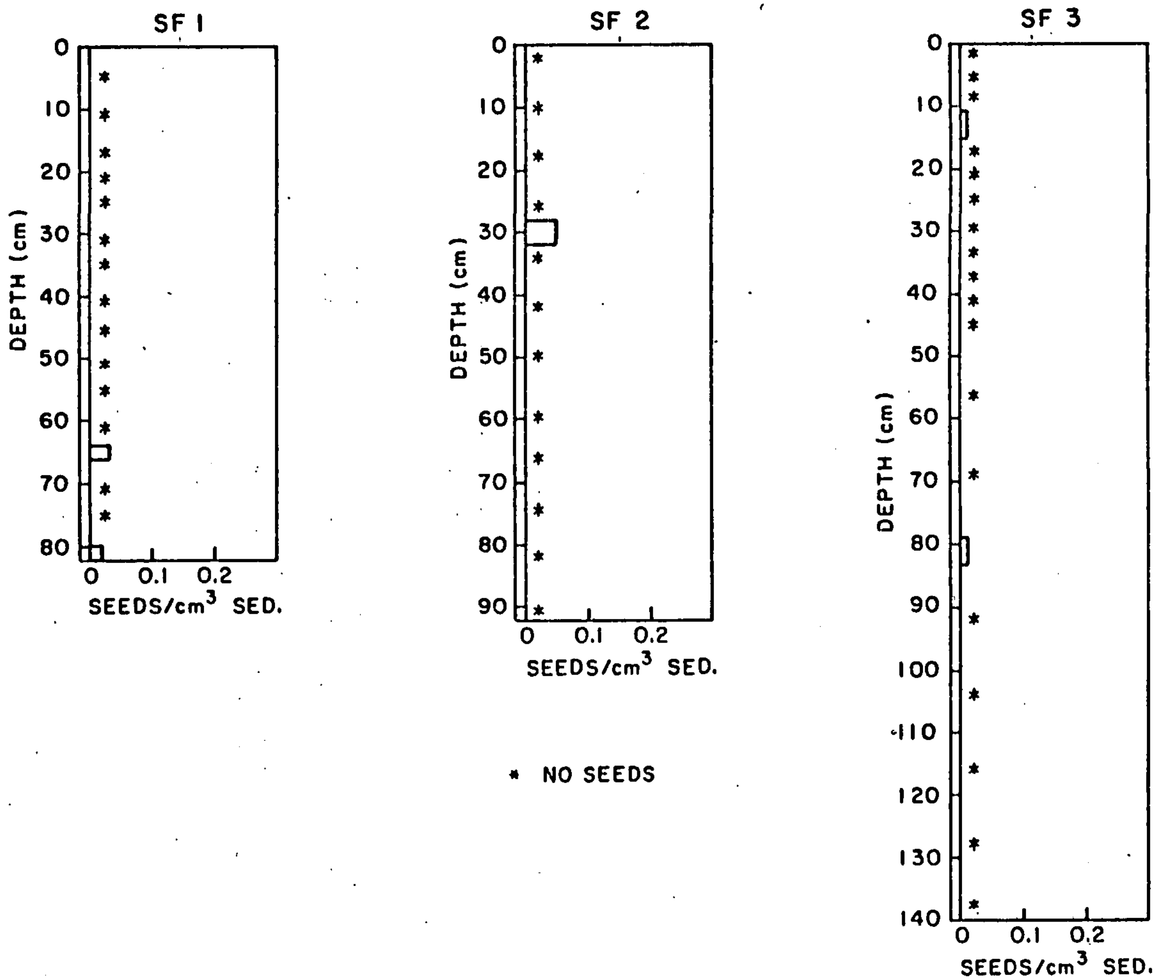


Figure 14. Seed concentrations of *Elodea canadensis* in cores from Susquehanna Flats.

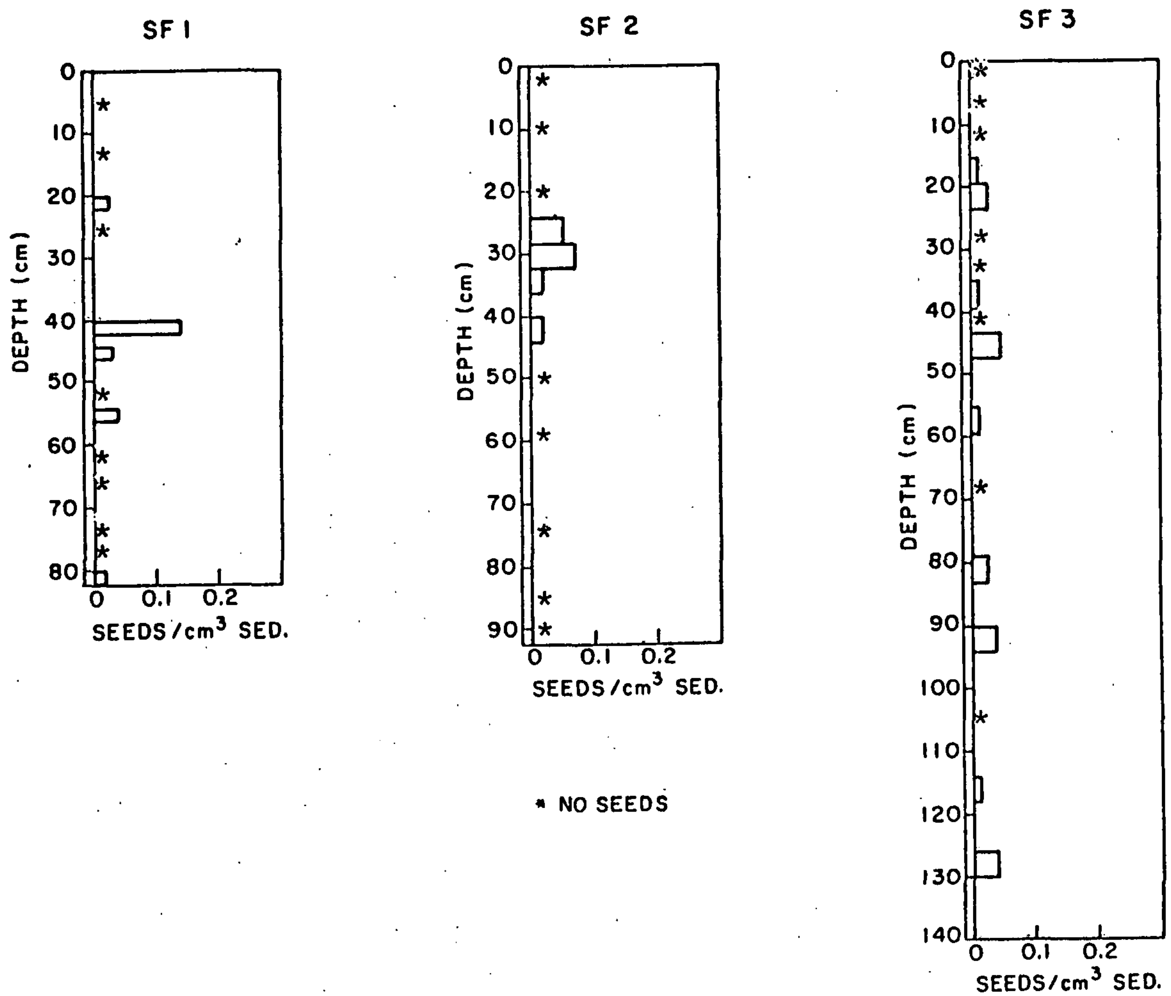


Figure 15. Seed concentrations of *Potamogeton spp.* in cores from Susquehanna Flats.

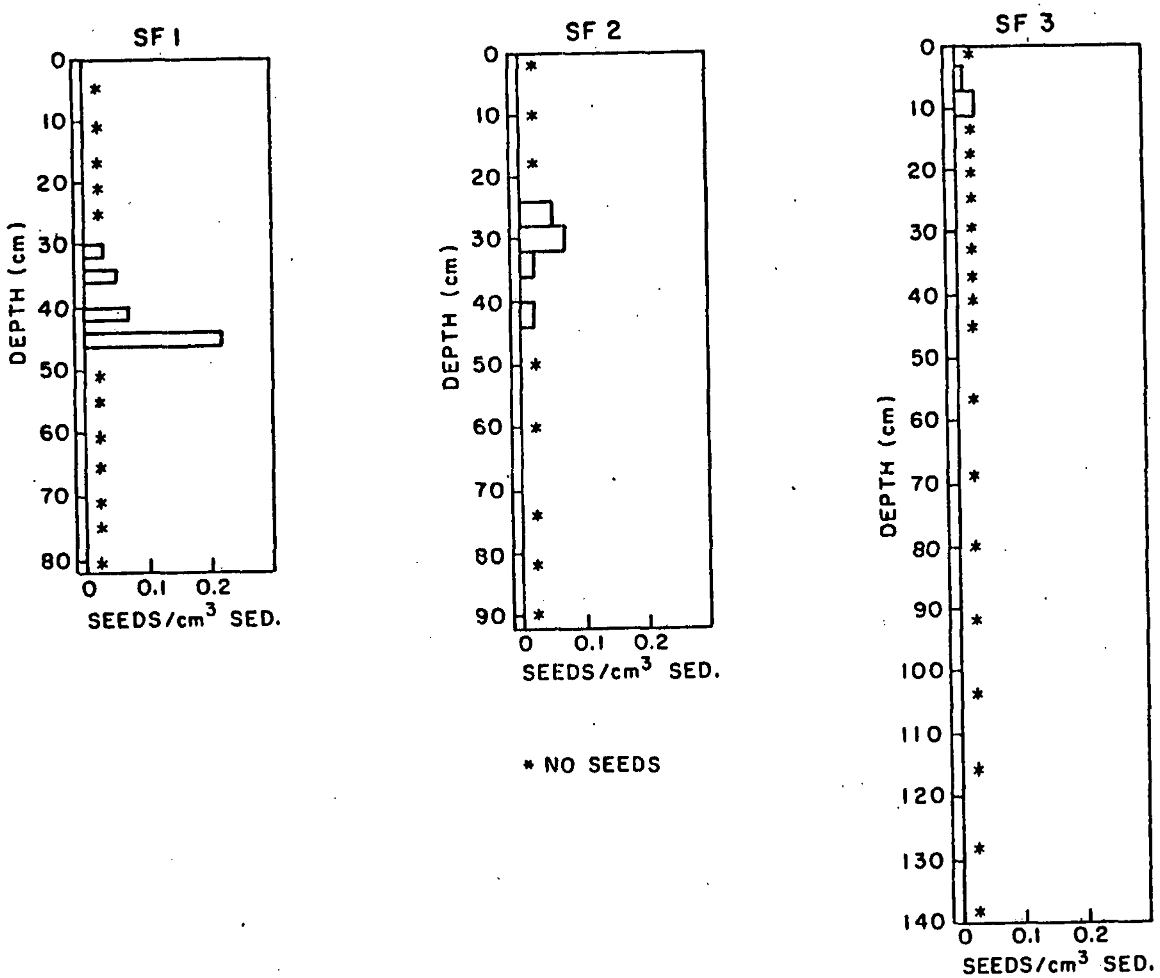


Figure 16. Seed concentrations of *Myriophyllum spicatum* in cores from Susquehanna Flats.

The cores contained seeds from 10 species out of 18 SAV species reported for this area (Bayley et al. 1978). *Najas quadalipensis, Heteranthera dubia, Ceratophyllum demersum, Potamogeton pectinatus* and *P. pusillus* each occurs only once, *Najas flexilis, P. gramineus, Vallisneria americana, Elodea canadensis* and *Myriophyllum spicatum* appear more regularly.

The greatest seed concentrations in Cores 1 and 2 coincide with a thick band of coal particles. The Core 1 band lies between 32 and 42 cm; the Core 2 band is between 24 and 32 cm. In both cores, this coal zone occurs directly above a band of coarse sand and below a layer of silt and terrestrial detritus. This pattern has been interpreted as the product of a major storm event, most likely the 1972 Hurricane Agnes. SAV seeds that were resuspended with upstream sediments apparently settled with the coal particles, producing a distinct peak in the seed profiles. The peak is especially prominent in the profiles for *Najas flexilis* (Figure 12).

In Core 3, the largest concentration of coal particles occurs between 3 and 7 cm though coal particles are apparent in all sediments above 98 cm. There is no abrupt climb in seed concentrations comparable to those in SF-1 and SF-2. *Najas flexilis* and *Vallisneria americana* appear consistently throughout the core. Seeds of *Potamogeton spp.* and *Elodea canadensis* occur sporadically, and *Myriophyllum* is limited to the top 12 cm.

The major shifts in local SAV populations which have been documented in field surveys since 1958 are not consistently depicted in the SAV record of the Susquehanna Flats. The dominant species are the same in both (*Najas sp., Myriophyllum spicatum, Vallisneria americana,* and *Elodea canadensis*), but there is nothing in the cores comparable to the simultaneous rise of *Myriophyllum* and decline of native grasses described in the MBHRL Survey during the early 1960's. The disappearance of SAV after Hurricane Agnes, on the other hand, is indicated by the absence of SAV seeds in surface sediments of all three cores.

It has been concluded that a dynamic area like the Susquehanna Flats is not amenable to SAV biostratigraphic study because:

1. Sedimentation patterns appear to vary greatly over small distances. As seeds would not be deposited uniformly under such conditions, an unrealistically large number of cores might be needed to reconstruct the long-term behavior of SAV.

2. At a site, sedimentation rates also fluctuate dramatically making it difficult to distinguish changes in seed concentrations due to changing sedimentation rates from changes which reflect trends in SAV populations. The possibility of periodic scouring of sediments at a location makes interpretations of seed assemblages still more difficult.

3. Pollen occurs in such low concentrations that palynologically derived sedimentation rates are difficult to obtain, and hence it may not be possible to compute a SAV flux in this area.

Similarity of diatom stratigraphy of the Susquehanna Flats and Furnace Bay implies that water quality is comparable in the two areas (Section 6). Furnace Bay is a good depositional area making it appropriate for biostratigraphic studies. Thus there may be indirect information on trends in SAV of the Flats which are related to changing water quality that can be inferred from Furnace Bay data. This is true only if SAV, which contribute to the Furnace Bay seed record, is responding to changes in water quality in a way that is representative of SAV in the area as a whole.

Furnace Bay

Furnace Bay is a broad, shallow embayment north of the Susquehanna Flats and east of the Susquehanna River (see Figure 3). Sediment enters Furnace Bay via Principio Creek, Mill Creek, Chesapeake Bay, and small streams which drain the immediate watershed. The sediments in all six cores taken from Furnace Bay are fine-grained (99 percent silt and clay) and relatively rich in organic matter. Unlike the sediments from the Susquehanna Flats, there is very little variation in sediment character with depth, which suggests that the cores are taken from undisturbed depositional areas.

Four of the six cores were analyzed. FB-I and FB-II were taken at sites 1 and 2; FB-III and FB-IV were taken less than 3 m apart at site 3 (Figure 3). All cores were collected with a 5.4 cm diameter piston corer.

FB-III and FB-IV were X-rayed by the Maryland Geological Survey; core sections X-rayed in FB-III showed banding patterns suggestive of undisturbed stratigraphy. Comparable sections in FB-IV had no distinguishable zonation. When all of the cores were split for subsampling, the gross structures of FB-I, FB-II and FB-III were generally similar but differed from FB-IV.

FB-I and FB-IV were divided into slices 2 cm thick and two slices were analyzed within every 10 cm along the core. Because seed concentrations were low, FB-II and FB-III were divided into 4 cm slices. In this pair of cores every sample was analyzed (Figure 11).

The methodology for seed extraction and enumeration is described in our Quality Assurance Report. FB-I and FB-II were analyzed for pollen and diatoms as well as seeds (Sections 5 and 6). FB-III was partially analyzed for pollen.

The seed data are presented as seed flux per 10 cm^2 per year in Figures 17 through 22. The seed flux is obtained by multiplying seed concentrations by sedimentation rates which were established through pollen analysis.

Seed data for FB-IV have been included and are adjusted to a sedimentation rate of 0.6 cm per year, even though sedimentation rates were not actually obtained for this core. Because FB-IV unquestionably has been mixed vertically, it is not included in the following discussion of Furnace Bay SAV stratigraphy.

BEGIN LAST LINE OF TEXT

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

3/8"

EPA-287 (Cin.)
(4-78)

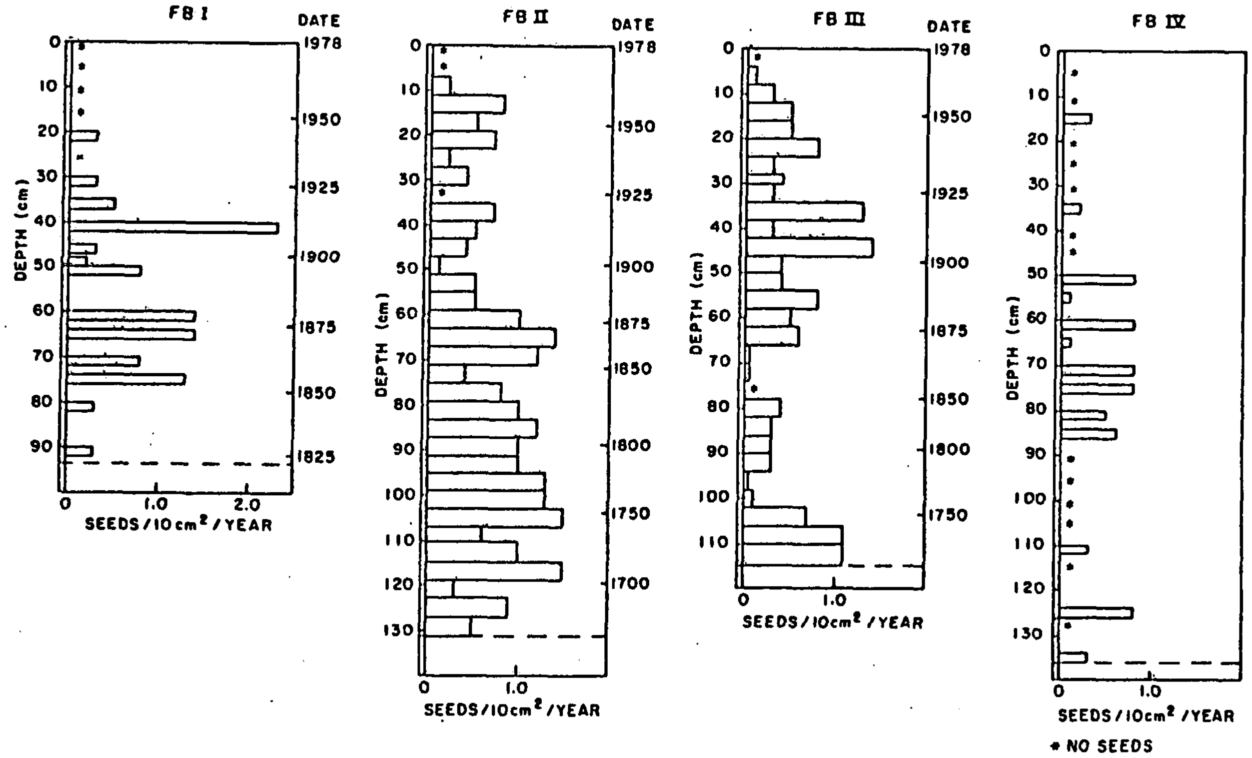


Figure 17. Seed flux of *Vallisneria americana* in cores from Furnace Bay.

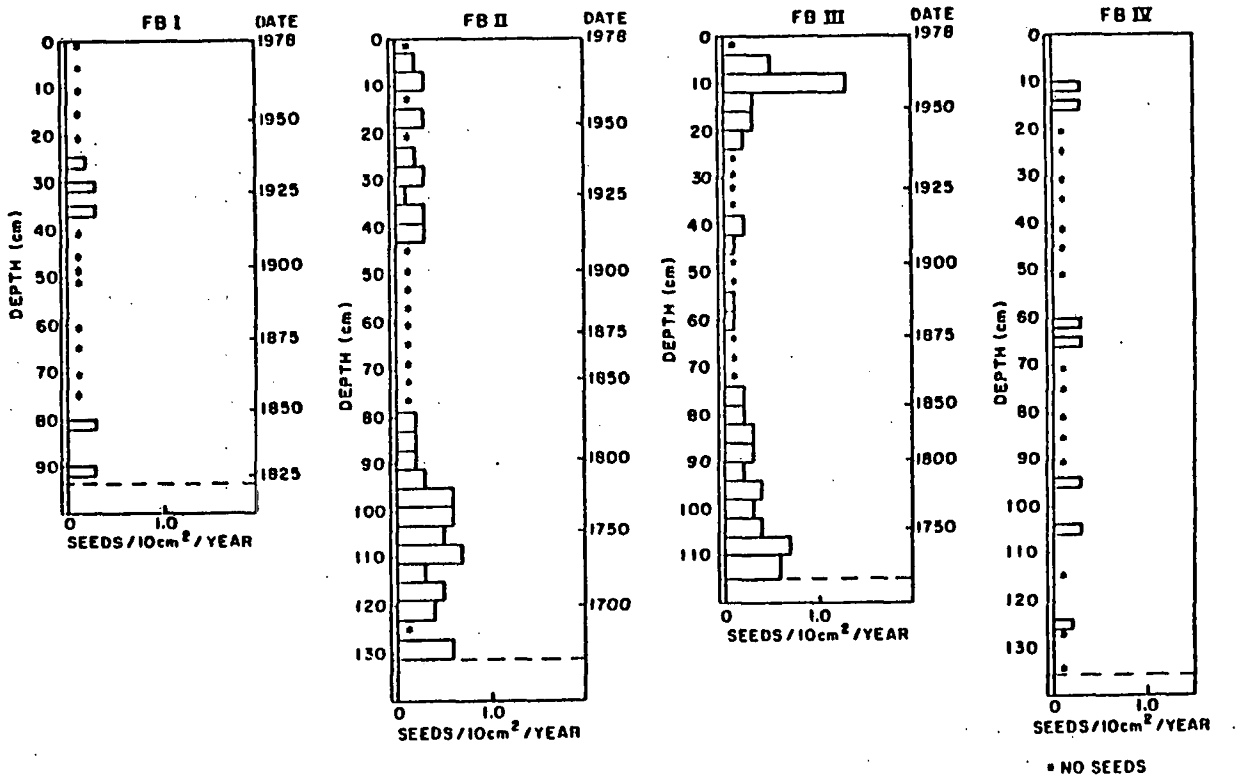


Figure 18. Seed flux of *Najas spp.* in cores from Furnace Bay.

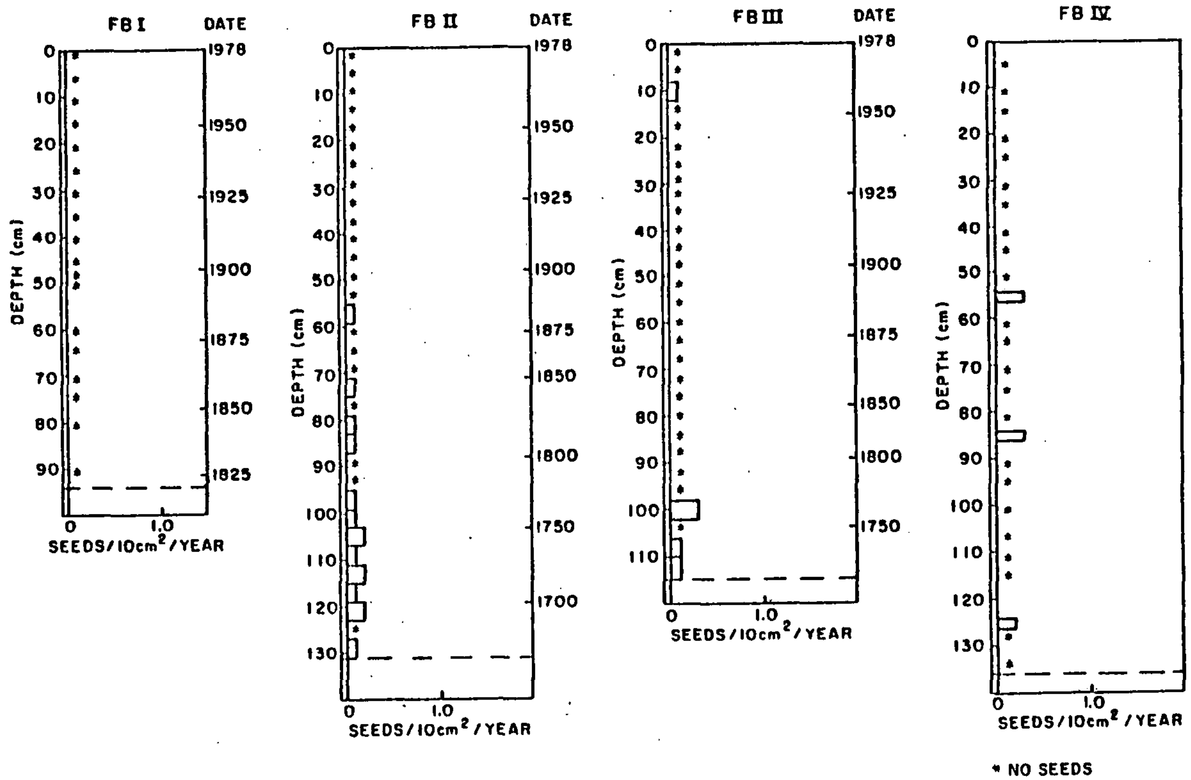


Figure 19. Seed flux of *Elodea canadensis* in cores from Furnace Bay.

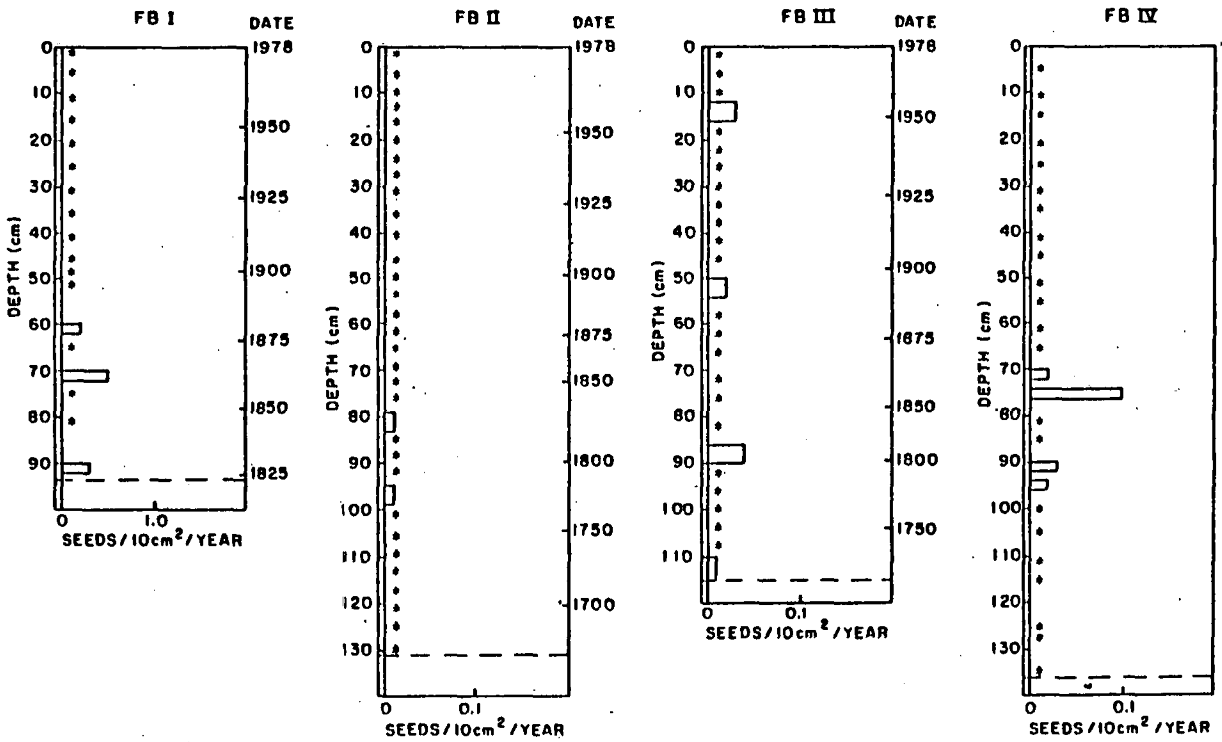


Figure 20. Seed flux of *Potamogeton spp.* in cores from Furnace Bay.

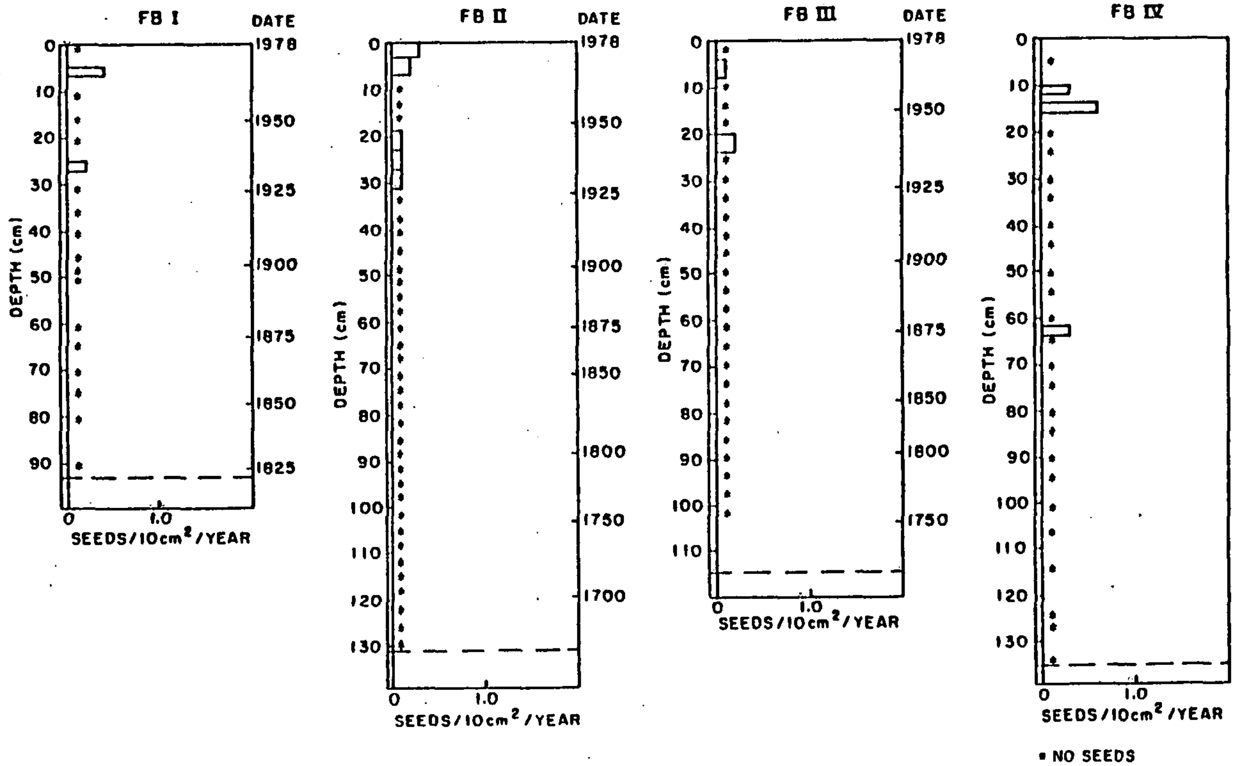


Figure 21. Seed flux of *Myriophyllum spicatum* in cores from Furnace Bay.

Vallisneria americana--

Seeds of *Vallisneria americana* occur regularly in relatively high concentrations in FB-I, FB-II and FB-III. There are few sediment depths at which *Vallisneria* seeds are low in all three cores.

No seeds occur in the surface sediments (0-3 cm) reflecting the disappearance of *Vallisneria* after Hurricane Agnes. Seed concentrations are uniformly low at depths corresponding to the years 1925-1930 (30-34 cm) and 1897-1902 (47-50 cm), intervals roughly coinciding with the major floods of 1936 and 1889. Total pollen flux in FB-I and FB-II does not change appreciably at these depths, so the drop in *Vallisneria* seed concentrations is probably not a function of sedimentation rate.

In 41 of 80 Furnace Bay samples, *Vallisneria* seeds occur in concentrations comparable to a flux rate of 0.5 seeds/10 cm^2/year or more. If these figures are representative, then over 500 seeds per m^2 per year have been deposited more or less regularly at the Furnace Bay coring sites during the past 300 years. In view of the relatively low seed production and localized dispersal patterns of SAV, it is believed that such a seed record could only derive from dense beds of *Vallisneria* growing inside Furnace Bay.

In general it appears that *Vallisneria* has grown continuously (or nearly so) in the area since the late 17th century. This implies that the species has persisted across periods of increased sedimentation (e.g., the late 19th century) and increased nutrient levels (following the onset of sewage discharge into Mill Creek). Steenis (1970) has found *Vallisneria* to be tolerant of "muddy roiled water" (Stevenson and Confer 1978).

Najas spp.--

The data for *Najas flexilis* and *N. quadalupensis* are grouped together in Figure 18 even though seeds of the species are easily distinguished. The profiles of the two species in FB-I, FB-II and FB-III are very similar, and their seeds occur in roughly equal numbers. Another reason for lumping the data is that field surveys usually group the two species since they are difficult to tell apart unless fruits are present.

Najas seeds are present in the oldest sediments of all three cores. They disappear simultaneously in the cores around 1840 (75-80 cm). They do not appear in concentrations comparable to pre-1840 until 1910 (above 42 cm). The failure of *Najas* to recolonize former habitats after Hurricane Agnes is shown by the absence of seeds from the most recent sediments.

The *Najas* seed profiles could be interpreted several ways depending upon the dispersal characteristics of the seeds. At one extreme, the Furnace Bay sediments could collect seeds from the Susquehanna Flats, Mill Creek and Furnace Bay itself, in which case a decrease in seed concentrations at a particular sediment depth would most likely describe a general decline of the species in the area. At the other extreme, the source of seeds could be vegetation in the immediate vicinity of the coring sites, in which case the seed flux would change dramatically with shifts in the distributions of *Najas* beds as well as with decreases in abundance in local beds.

Several observations suggest that the ~~trends observed in the Furnace Bay cores are products of more than a local reshuffling~~ of SAV beds, and that species of *Najas* were less abundant between 1840 and 1910 in an area at least as large as Furnace Bay. These observations are:

1. The same trends in the *Najas* seed flux are apparent in all three Furnace Bay cores.

2. If the *Najas* record were extremely local, one would expect some amount of reciprocity in the seed records of *Najas* and *Vallisneria*. In fact, the seed records of *Najas spp.* and *Vallisneria* act independently or similarly, probably as a function of changing sedimentation rates.

3. *Najas flexilis* reproduces primarily sexually. It therefore produces many seeds that are capable of being dispersed over large distances (Birks 1972, Stark 1975). *N. guadalupensis* apparently behaves similarly (Stevenson and Confer 1978). Thus in spite of high sedimentation rates in the Susquehanna Flats, the cores from that area (SF-1 and SF-3) contain *N. flexilis* seeds in relatively high concentrations. The moderate to low concentrations of *Najas spp.* seeds in Furnace Bay sediments lead us to suspect that *Najas spp.* if present, have not dominated the vegetation in the vicinity of the coring sites. Consequently, the seeds could be coming from a more distant part of Furnace Bay or perhaps floating in from the Susquehanna Flats.

4. The decrease in *Najas* seed flux continues for 70 years.

In circumspect, the *Najas* profiles might represent the disappearance from and eventual return to Furnace Bay of small local populations. They also could represent a decline in the species over a larger area than Furnace Bay--perhaps over an area extending into the northern Susquehanna Flats.

The decline in the abundance of *Najas spp.* coincides with a period when suspended sediments were probably at high levels in the Susquehanna River as a result of extensive deforestation in the watershed. We know of no data that suggest *Najas spp.* are especially intolerant of increases in turbidity. In fact, *Najas spp.* can grow in lower light conditions than many other SAV species (Martin and Uhler 1939). There may have been associated changes in water or sediment quality of the area which adversely affected the *Najas* populations. Species of *Najas* occur on a wide variety of substrates, although they thrive in predominantly sandy sediments (Stevenson and Confer 1978).

Elodea canadensis--

With the exception of one seed at 8-12 cm in FB-III, the recent sediments of Furnace Bay do not contain any seeds of *Elodea* (Figure 19). Seeds occur consistently in low numbers in FB-II until 1780 (95 cm), sporadically until 1890 (55 cm), and then disappear altogether. In FB-III, the species disappears from the record by 1760 (97 cm). No *Elodea* seeds are contained in FB-I. (Sediments from this core are younger than 1810.)

Elodea was a prominent member of SAV communities of the Susquehanna Flats between 1958 and 1971 (Bayley et al. 1978). Judging by the seed profiles, the plants which grew in the Flats during that time did not contribute much to

Furnace Bay seed assemblages. This is probably due in part to *Elodea*'s low seed output (the species reproduces primarily asexually). Thus the seed record from 18th century sediments probably describes relatively dense beds of *Elodea* in or near Furnace Bay which ~~declined around the time the surrounding area was cleared for agriculture~~. This is somewhat enigmatic since ~~*Elodea* generally does well in areas of high sedimentation~~ (Stevenson and Confer 1978).

Potamogeton spp.--
The *Potamogeton* species have been grouped because fragments of seeds are not always identifiable to species. Most of the seeds which can be identified belong to *P. gramineus* (Figure 20).

Seeds are probably not a good indicator of former *Potamogeton* beds, since they suffer high rates of predation by waterfowl and may not preserve well in the sediments. There are no sediment depths which show consistent trends in all cores. However, the leaf record indicates that *P. gramineus* may have had a long tenure in the area.

Myriophyllum spicatum--
Myriophyllum did not figure prominently in the SAV communities of the Upper Bay until the late 1950's, despite its introduction into the United States in 1895. Between 1957 and 1959, the percentage of sampling stations at which *Myriophyllum* was recorded jumped from 0 to 47 percent (Bayley et al. 1978).

The first *Myriophyllum* seeds appear in FB-II at 30 cm and in FB-I and FB-III at 26 cm and 24 cm (the *Myriophyllum* seed at 64 cm in FB-IV is taken as further evidence that this core has been vertically mixed). If 1959 is considered as the year *Myriophyllum* first appeared, then the seed record from Furnace Bay implies a sedimentation rate of 1.3 cm/year which is twice as high as the rate determined for Furnace Bay by pollen analysis. If we accept the sedimentation rates provided by pollen analysis, then *Myriophyllum* would have occurred in Furnace Bay as early as 1930.

CONCLUSIONS

SAV seed assemblages in sediments from Leeds Creek, the Susquehanna Flats and Furnace Bay reflect former beds of dominant SAV. The assemblages are a function of the species composition of former beds as well as the local hydrological patterns influencing seed deposition. The data show that the SAV record represents local populations and that there is large variability in the annual SAV seed flux within a locale.

In designing a sampling program to study past distributions of SAV, there is a trade-off between the number of cores that can be studied from an area and the resolution at which any single core can be analyzed. This is so because considerable time is involved in the analysis of any one core for SAV seeds. Since spatial variability may mask any minor temporal trends, the recommendation is to take several cores from a locale and divide each core into a practically small number of samples so the major trends in dominant SAV over time are defined. The number of samples needed to divide the core into such time intervals will vary with the sedimentation rates characteristic of the study area.

The results also suggest that an impractically large number of cores would be required to study the history of SAV populations using a sampling program designed on a regional scale. Instead, sites should be chosen within a tributary that are likely to reveal responses of local SAV populations to regional changes in water quality due to increased sedimentation, eutrophication, etc. This means that cores should be taken from good depositional areas strategically located within the tributary (e.g., upstream and downstream from point sources of nutrients, in areas now devoid of SAV which had good SAV populations in the past, etc.). If the same dominant SAV populations show similar trends in a few local areas subjected to similar regional impacts, some conclusions may be drawn about the effect of different kinds of watershed disturbance (land use) and water quality on SAV.

SECTION 5

SEDIMENT TRANSPORT AND DEPOSITION

INTRODUCTION

The fate of toxics and other substances transported into the tributaries and main stem of the Bay are governed to a large extent by the transport of sediment and its rate of deposition. Sedimentation rates indicate which areas are filling in, how rapidly, and the influence of land use in different watersheds on the amount and rate of sediment deposited in the receiving water. Sedimentation rates are necessary also for calculating the true deposition rate (flux) of seeds and diatoms.

Sedimentation rates can be obtained by measuring the decay rates of ^{210}Pb and ^{14}C in the sediments. They also are calculated from exact dates assigned to sedimentary horizons where there is a major change in the composition of the pollen assemblage originating from terrestrial plants. Pollen grains of terrestrial plants are well preserved in sediments and reflect major changes in the composition of the vegetation caused by climatic change, disease and land use. Since the time of European settlement layers of sediment deposited that exhibit vegetational changes resulting from changing land use often can be dated from historical records. Where the land use has been manifold, several horizons may be dated in a core if it extends to presettlement time or includes sediments deposited since early settlement. While the maximum resolution of ^{210}Pb is approximately 1 to 100 years and ^{14}C approximately 500 to 100,000 years, pollen does afford a means of dating sediments too old or too young to be dated radiometrically. In this study, all sedimentation rates were based upon pollen analyses. Cores are being analyzed also that are dated by ^{210}Pb from both the Potomac River and Chesapeake Bay in order to compare the two methods of dating.

In this study, two of three questions were addressed, more or less fundamental to establishing a data base of sedimentation rates for the Chesapeake Bay system. It was sought to determine (1) the number of cores at a location and throughout the length of an estuary necessary for obtaining data representative of the pollen deposited at a given time, and (2) the integrity of the vertical distributions of pollen as well as the number of horizons that can be dated using changes in sedimentary pollen assemblages. So far, the question of the effect of compaction of estuarine sediments on sedimentation rates has been left unanswered. This problem is being investigated with the object of determining whether or not correction factors for compaction of different sediment types are necessary for describing a true sedimentation rate.

In addition to providing information on the variability between samples, the data obtained for determining the necessary number of cores also provided information on the distance some sediment is transported within the estuary.

SPATIAL DISTRIBUTIONS OF POLLEN IN ESTUARINE SEDIMENTS

Pollen distributions and hence the spatial variation of pollen in estuarine sediments are governed by (1) the distribution, pollen production, time of flowering and pollination mechanisms of the source vegetation, (2) the processes operating in the atmosphere and within the river including the dynamics of transport, deposition, resuspension and redeposition, and (3) the physical characteristics of the pollen controlling its susceptibility to the transport phenomena.

An interpretation of pollen assemblages in surface sediments in terms of the interaction of these three factors will allow a better understanding of what a pollen assemblage at any one locality in the estuary represents in terms of vegetation type and land use. Thus, this would provide a basis on which to interpret vertical changes in pollen assemblages with respect to vegetation and land use in the past.

In order to accomplish this objective, the spatial distribution of pollen in surface sediments in the tidal stretch of the Potomac River is described in order to (1) identify the best depositional locations and the number of samples necessary to obtain data representative of the vegetation, (2) determine the area of source vegetation represented by pollen in the surface sediment at any one location including the accuracy of the representation so that we might know the area for which historical records are needed to date changes in the vertical pollen profile, and (3) determine the effect of estuarine transport processes on the pollen distributions.

In order to accomplish the first objective, comparisons were made of the total number of grains per gram dry sediment in the channel and nonchannel samples, the percent of total pollen of all the tree pollen types identified in channel and nonchannel samples; the degree of similarity with respect to percents of all pollen types between all channel samples was examined, and the amount of variability that occurs between samples taken at the same location was tested. Addressing the second objective, the degree of abundance of the pollen types whose source vegetation occurs far upstream of the surface sediment samples was observed, percents of total pollen were compared with the respective percents of total basal area in the adjacent vegetation and efforts were made to detect any spatial trends in the pollen and/or vegetation. Finally, with regard to the third objective, the degree of scatter observed in the pollen of the surface sediments was compared with the degree of scatter in the vegetation and the distribution of the pollen in relation to their physical characteristics was investigated.

The tidal Potomac River was chosen for this phase of the study because additional support was obtained from the U. S. Geological Survey for the study, including collection of samples, which required 1 week of boat time, and analysis of samples. It was felt that results from the tidal Potomac

River with regard to the movement of small particles such as pollen and their spatial distributions in the sediments would be applicable generally to all tributaries, and it would at the very least provide guidelines for sampling in the other tributaries.

Surface sediments were collected with a Shipley sediment sampler at 139 locations in 28 transects across the Potomac River from Alexandria, Virginia to Point Lookout where the river enters the Chesapeake Bay. This stretch includes almost all of the tidal Potomac. Triplicate samples were taken at two transects. Of the samples collected, 48 from 13 transects and one set of triplicates were analyzed (Figure 22).

Vegetation data used were collected in 1974 for compilation of a map of the woody vegetation of Maryland (Brush et al., in press). The data consist of basal area measurements of trees greater than 2 cm dbh* in 132 400 m^2 plots located in 43 7-1/2 minute quadrangles (Figure 22). Plots are located more or less randomly within the quadrangles; the number of plots in each quadrangle is given later in Table 13 (page 66). The area chosen as a source for the pollen is adjacent to the stretch of the river studied and extends eastward to the Chesapeake Bay (Figure 22). Forest associations are separated by the presence or absence of loblolly pine, basket oak, willow oak, blackjack oak, post oak, tulip poplar, river birch and sycamore. (See Brush et al., in press, for the distributions and species composition of forest associations throughout Maryland.) Although many of the forest associations are separated on the basis of different species of the same genus and most pollen are not identifiable to species, the potential exists for identifying in the pollen assemblages those associations that are characterized by different genera. For example, sweet gum is closely associated with loblolly pine. Both types drop out of the vegetation further north and west where the forest associations include entirely different genera such as basswood, hemlock and sugar maple. The latter do not occur in our designated source area. Unfortunately, similar data do not exist for the Virginia side of the Potomac, but the major species are more or less similar. The area studied is approximately 40 percent forested. Pollen types are plotted in Figure 23.

Deposition of Pollen in the Estuary

The first attempt was to assess whether there is a difference between the channel and nonchannel zones of the river with respect to pollen deposition. Out of the 20 channel samples analyzed, all contained sufficient pollen grains to produce pollen assemblages while 19 out of 28 (68 percent) of the nonchannel samples contained an adequate amount. An arbitrary number of 5,000 to 10,000 grains per gram dry sediment was chosen as the minimum amount of pollen upon which to compile an assemblage. In one case, 5,000 was adequate because numerous types were present; in other cases 8,000 to 9,000 were considered inadequate because the assemblage included only one or two types and the grains were broken. All samples containing greater than 10,000 grains were included in the study.

*dbh = diameter at breast height.

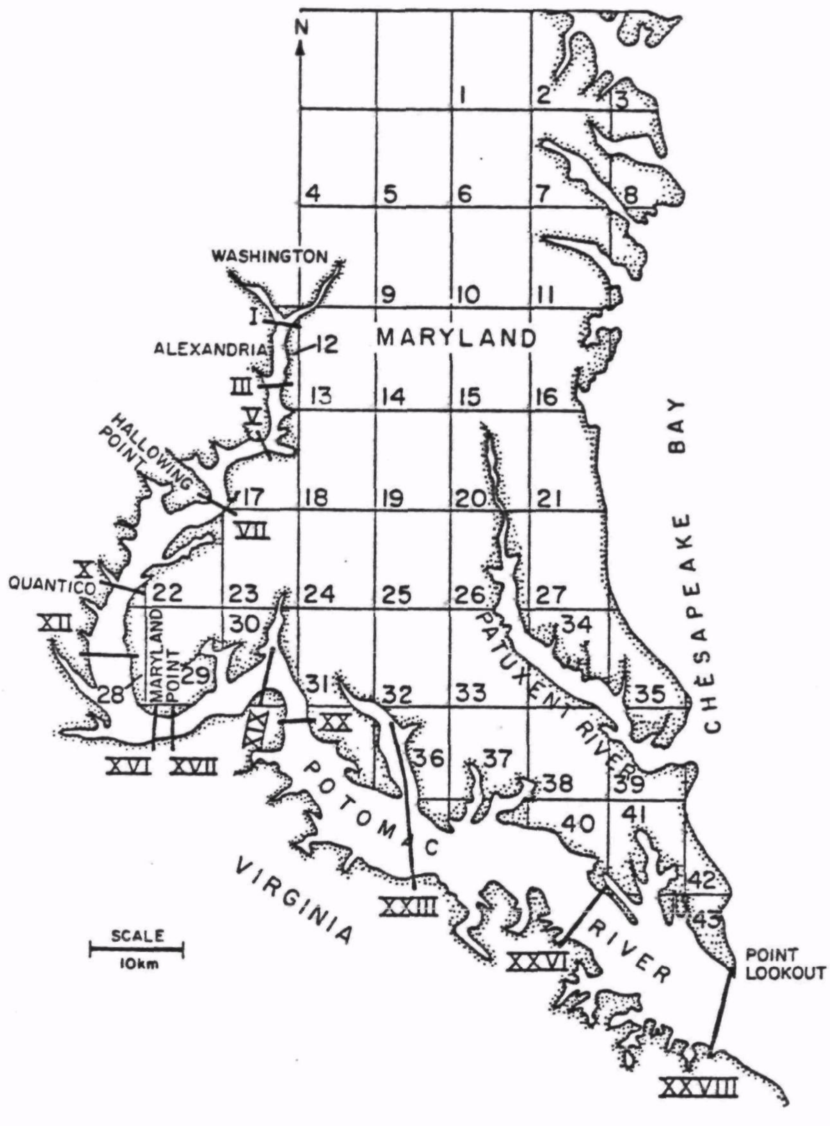


Figure 22. Locations of surface sediment transects for pollen distributions in the Potomac River and locations of quadrangels used as the vegetation source for the pollen.

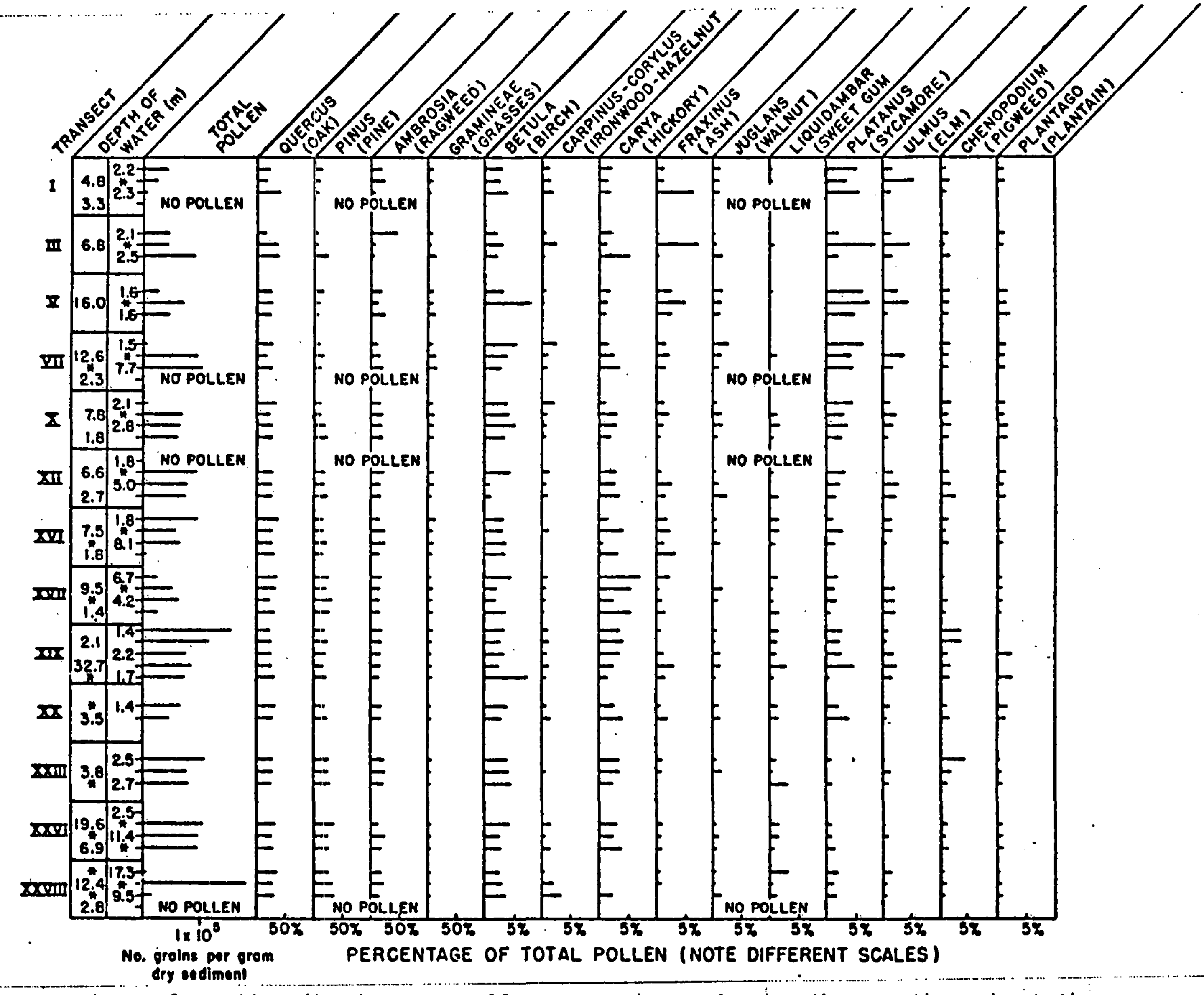


Figure 23. Distributions of pollen types in surface sediments throughout the tidal stretch of the Potomac River. * denotes channel samples.

The next test was whether there is selective deposition of the tree pollen between channel samples and those nonchannel samples with adequate numbers of pollen for the compilation of assemblages.

The results of a rank-sum test (Hollander and Wolfe 1973) performed for each tree pollen type, where the null hypothesis is that the percent of total pollen of each type in the nonchannel samples is from the same population as the percent of total pollen for each type in the channel samples, indicates that percents of total pollen of hickory, beech, holly and cherry are higher at the 0.06 significance level in the nonchannel samples. The percent of total pollen of ironwood-hazelnut is lower in the nonchannel samples at the 0.09 significance level. For the remaining types the null hypothesis is accepted, i.e., there is no significant difference between populations in channel and nonchannel samples.

The observation that only a few pollen types may be selectively deposited, along with the consistent occurrence of large numbers of pollen grains in the channel samples, indicates that the channel is the favorable zone of deposition in the estuary for most pollen grains. Consequently, we restrict all analyses relating pollen to vegetation to data from channel samples.

The degree of similarity between pollen assemblages in the channel samples when considering all of the identified pollen types from Tables 8 and 9 together, irrespective of their frequency of occurrence was next considered. Table 10 shows Sorensen's similarity indices, which range between 0 (no similarity) and 100 (complete similarity). For values greater than about 75, the two samples may be considered replicates (Mueller-Dombois and Ellenberg 1974).

Since the index of similarity between all the channel samples taken within the same transect (boxed values in Table 10) are greater than 75, it is inferred that it is not necessary to take more than 1 sample at any one transect. Furthermore, most of the similarity indices between samples from Transects I through XVI and between samples from Transect XVI through XXVII are greater than 75. Thus, taking only two samples, one in the vicinity of Transect I - XVI and one in the vicinity of Transect XVI - XXVIII, would yield a fairly adequate picture of the pollen assemblages in this stretch of the river. Local effects, such as sporadic pollen input from the vegetation or localized deposition, do not, to any great extent, mask the pollen representation of the regional vegetation at any one locality and thus would not mask regional changes in land use. Therefore, pollen in the tidal portion of an estuarine depositional basin may provide an overall view of the regional vegetation without the necessity of analyzing numerous samples.

The degree of similarity that occurs between samples taken at the same location was then tested. Three sets of four samples were taken at Transect VII by running the boat across the transect three times and attempting to sample each of the locations at the identical place each time. The two triplicate samples taken in the nonchannel zone did not contain an adequate number of pollen grains to analyze. The indices of similarity for

TABLE 8. PERCENT OF TOTAL POLLEN IN CHANNEL SAMPLES AND PERCENT OF TOTAL BASAL AREA IN THE DESIGNATED SOURCE AREA OF ALL TREE SPECIES WITH > 0.001 PERCENT BASAL AREA

Scientific name	Common name	Frequency in channel samples (%)	Total pollen (%) (n=20)		Total basal area (%) (n=20)	
			Mean	S.D.	Mean	S.D.
Acer rubrum	red maple	40	0.2	0.3	5.7	9.9
Acer negundo, A. saccharinum	maple	55	0.6	0.8	1.1	78.1
Ailanthus altissima	tree-of-heaven	0		-0-	0.2	7.0
Betula nigra	birch	100	3.6	1.6	2.9	11.5
Carpinus caroliniana, Corylus americana†	ironwood-hazelnut	95	1.1	0.9	0.9	4.0
Carya cordiformis, C. glabra, C. illinoense, C. laciniosa, C. ovalis, C. ovata, C. pallida, C. tomentosa	hickory	95	2.5	1.3	2.4	5.4
Celtis occidentalis	hackberry	35	0.2	0.4	-0-	---
Cornus florida	dogwood	15	0.1	0.1	1.1	2.3
Fagus grandifolia	beech	65	0.3	0.4	3.8	9.9
Franxinus americana, F. pennsylvanica, F. pennsylvanica var. subintegerrima	ash	90	1.4	1.7	1.0	4.3
Ilex opaca	holly	35	0.1	0.2	2.1	4.3
Juglans nigra	walnut	100	0.8	0.4	<0.1	---
Juniperus virginiana	red cedar	65	0.4	0.5	0.1	0.5
Liquidambar styraciflua	sweet gum	95	1.1	0.9	9.1	13.9
Liriodendron tulipifera	tulip poplar	0	-0-	---	11.2	22.2
Magnolia virginiana	magnolia	0	-0-	---	0.1	0.9
Morus rubra	mulberry	30	0.2	0.3	-0-	---
Nyssa sylvatica	black gum	40	0.2	0.3	3.3	5.5
Pinus taeda, P. virginiana	pine	100	19.4	8.0	14.6	23.8
Platanus occidentalis	sycamore	100	2.7	2.2	1.0	4.0
Populus grandidentata	aspen	0	-0-	-0-	0.1	0.7
Prunus serotina, P. virginiana,	cherry	25	0.1	0.3	0.6	2.4
Quercus alba, Q. coccinea, Q. falcata, Q. marilandica, Q. michauxii, Q. nigra, Q. palustris, Q. phellos, Q. Prinus, Q. rubra, Q. stellata, Q. velutinea	oak	100	26.4	4.8	33.1	2-.1
Robinia pseudo-acacia	black locust	0	-0-	---	1.3	5.6
Sassafras albidum	sassafras	0	-0-	---	0.4	1.7
Ulmus americana, U rubra	elm	100	1.8	1.5	1.7	6.9
Tilia americana	basswood	20	0.1	0.2	-0-	---
Tsuga canadensis	hemlock	60	0.3	0.3	-0-	---

*All of the species occurring in the source vegetation > 0.001% of total basal area are listed. Pollen cannot be identified to species generally. Therefore a pollen type (genus) can include species other than those listed that occur outside of the designated source area.

†*Carpinus* and *Corylus* were combined because the pollen is difficult to separate.

TABLE 9. PERCENT OF TOTAL POLLEN OF ALL SHRUB AND HERBACEOUS TYPES

Scientific name	Common name	Frequency in channel samples (%)	Total pollen (%) (n=20) Mean	S.D.
Ambrosia	ragweed	100	16.1	4.5
Caprifoliaceae	honeysuckle family	5	0.02	0.09
Caryophyllaceae	pink family	10	0.02	0.06
Chenopodium	pigweed	100	1.0	0.3
Cruciferae	mustard family	45	0.2	0.3
Cyperaceae	sedge family	50	0.17	0.2
Drosera	sundew	5	0.01	0.04
Equisetum	horsetail	5	0.01	0.04
Ericaceae	heath family	15	0.04	0.11
Filicineae	ferns	30	0.2	0.35
Galium	bedstraw	5	0.01	0.04
Gramineae	grass family	100	5.0	3.3
Impatiens	jewelweed	15	0.07	0.2
Leguminosae	legume family	25	0.09	0.16
Ligustrum	privet	45	0.2	0.3
Liguliflorae	composites	20	0.9	3.6
Lonicera	honeysuckle	5	0.015	0.07
Lycopodium	club moss	25	0.06	0.1
Myriophyllum	milfoil	40	0.14	0.3
Nympheaceae	water-lily family	10	0.05	0.11
Osmunda	flowering fern	10	0.025	0.08
Plantago	plantain	100	1.0	0.5
Polygonaceae	buckwheat family	30	0.18	0.3
Potamogeton	pondweed	15	0.04	0.09
Papaveraceae	poppy family	5	0.01	0.04
Primulaceae	primrose family	10	0.1	0.5
Ranunculaceae	buttercup family	25	0.09	0.17
Rhamnus	buckthorn	60	0.3	0.4
Rhus	sumac	35	0.15	0.2
Rosaceae	rose family	45	0.4	0.5
Rumex	sorrel	85	0.7	0.5
Sambucus	elderberry	5	0.03	0.13
Saxifragaceae	saxifrage family	5	0.015	0.07
Salix	willow	85	0.5	0.4
Solanaceae	nightshade family	15	0.06	0.16
Solidago	goldenrod	5	0.02	0.09
Sphagnum	sphagnum moss	40	0.11	0.15
Tubuliflorae	composites	75	0.6	0.5
Typha	cattail	45	0.2	0.2
Umbelliferae	parsley family	55	0.2	0.2
Urtica	nettle	5	0.02	0.09
Vaccinium	blueberry	5	0.01	0.04
Viburnum	viburnum	15	0.03	0.07
Violaceae	violet family	20	0.16	0.4
Zea	corn	15	0.05	0.13

TABLE 10. MATRIX OF INDEX OF SIMILARITY IN PERCENT FOR CHANNEL SAMPLES (INDEX OF SIMILARITY = 2W/A+B, WHERE A = SUM OF ALL VALUES OF PERCENT OF TOTAL POLLEN FOR ALL TYPES, B = SUM OF ALL VALUES OF PERCENT OF TOTAL POLLEN FOR ALL TYPES IN SAMPLE BEING COMPARED. W = SUM OF SMALLER OF THE TWO VALUES OF THE PERCENT OF TOTAL POLLEN FOR ALL TYPES IN THE TWO SAMPLES BEING COMPARED. BOXED VALUES INDICATE THAT THE INDEX OF SIMILARITY IS BETWEEN SAMPLES TAKEN IN THE SAME TRANSECT.)

Sample	I-2	III-2	V-2	VII-2	VII-3	X-2	XII-2	XVI-2	XVI-3	XVII-2	XVII-3	XIX-8	XX-2	XXIII-8	XXVI-2	XXVI-3	XXVI-4	XXVIII-2	XXVIII-3	XXVIII-4
I-2																				
III-2	94.9																			
V-2	90.6	77.2																		
VII-2	76.2	61.5	71.5																	
VII-3	79.5	65.3	76.8	86.0																
X-2	79.6	62.9	73.2	81.4	87.1															
XII-2	78.7	60.2	69.8	78.0	82.6	84.5														
XVI-2	75.6	62.7	72.7	77.0	82.7	83.4	88.5													
XVI-3	72.1	55.5	66.9	71.4	75.7	77.7	83.4	84.4												
XVII-2	66.1	61.9	65.8	73.0	75.2	73.7	79.8	79.1	76.2											
XVII-3	62.9	58.1	64.8	70.0	70.8	68.9	74.4	75.5	76.2	80.3										
XIX-8	64.5	63.0	60.5	69.4	71.9	71.9	77.0	78.2	79.2	77.2	76.5									
XX-2	69.8	63.7	68.3	72.0	77.9	78.2	82.9	86.1	81.5	81.6	77.6	82.9								
XXIII-8	66.0	55.6	64.3	66.3	72.0	74.7	81.5	81.2	82.8	72.4	78.5	79.4	83.2							
XXVI-2	58.1	60.3	62.4	64.5	65.1	66.7	70.6	63.3	72.6	74.4	84.8	81.4	80.6	81.5						
XXVI-3	66.5	47.9	62.5	66.2	73.1	73.8	81.1	83.6	87.6	76.3	77.7	80.1	84.1	77.1	76.8					
XXVI-4	65.9	59.8	65.3	67.9	76.3	74.6	80.1	83.9	84.0	80.6	80.2	82.2	84.7	85.9	82.6	87.7				
XXVIII-2	58.2	64.2	61.7	62.0	66.4	66.1	72.1	74.2	74.7	78.4	76.9	78.6	80.7	81.3	79.4	78.7	83.4			
XXVIII-3	67.6	54.1	48.7	64.2	70.3	72.3	78.7	80.2	81.8	74.2	85.0	78.1	79.1	87.1	83.6	84.8	85.7	75.9		
XXXVIII-4	57.0	59.1	60.6	65.8	64.6	65.5	71.2	73.8	78.4	76.2	84.2	76.9	80.3	81.1	88.4	79.2	82.6	78.4	84.2	

Sample	2A	2B	2C	3A	3B	3C
2A						
2B	79.6					
2C	78.9	84.0				
3A						
3B				79.4		
3C				78.1	88.6	

Index of similarity in percent for triplicate samples at Transect VII the triplicate samples at the two channel locations are all greater than 75 (see Table 10), indicating that the data from one sample at a location may be representative of the pollen assemblage at spot.

Relationship Between Pollen in Sediments and Source Area

Only tree species were used in analyzing relationships between pollen assemblages and source vegetation because the vegetation data are restricted to tree and shrub species.

In order to estimate the areal extent of the source vegetation, the observation was made that the distributions of the pollen of maple (other than red maple, the pollen of which is easily distinguishable from other species), basswood and hemlock occur in very low frequencies in the pollen assemblages. These trees are not present in the area chosen as the source vegetation (Table 8). This indicates that pollen is not being transported into the tidal Potomac from the Upper Potomac which drains the Appalachian province in Maryland where sugar maple constitutes approximately 35 percent of large forested areas, hemlock approximately 17 percent, and basswood approximately 7 percent (percent basal area of total basal area of these particular associations). Maple pollen, not identified as red maple, probably represents silver maple which grows on floodplains in the area studied. Although sediments have not been sampled in the Upper Potomac in the vicinity of the sugar maple - basswood and hemlock - birch forests, sediments from the Upper Chesapeake Bay draining similar forest regions in Pennsylvania (via the Susquehanna River) contain large amounts of maple , hemlock, and birch pollen (described later in this section). In the Potomac sediments, birch pollen occurs in low numbers, although consistently, comparable to the percent basal area of river birch growing along the river. Thus the pollen occurring in the sediments appears to represent fairly closely the vegetation of the area chosen as the source. This provides justification in the expectation that the vegetation of the study area bears some relation to the pollen in the sediments, and it would constitute the area where changes in the vegetation due to land use would be reflected by changes in the stratigraphic pollen assemblages.

Tables 8 and 9 listed all of the pollen types occurring in the channel samples with their frequency of occurrence and percents of total pollen. Percents basal area for each tree species greater than 0.001 percent of total basal area are listed. Frequency of occurrence and percents of total pollen of shrub and herbaceous pollen are listed in Table 9. Total grains per gram dry sediment and percents of total pollen of pollen types occurring in at least 90 percent ofthe channel samples are plotted on Figure 23.

Except for tulip poplar and sweet gum, there is a reasonably close correspondence between percent basal area of many of the species occurring in the source area and percent of total pollen of respective pollen types in the sediment. Some of the less abundant trees are over and underrepresented (Table 8). The result is surprising in the light of differential pollen production both between and within tree types and the differential transport and deposition of pollen grains (Brush and Brush 1972, Davis, Brubaker and Beiswenger 1971). A comparison of these values with those shown for other depositional environments (e.g., Davis and Goodlett 1960, Livingstone 1968, Crowder and Cuddy 1973) indicate that R-values (pollen-tree ratios) are related strongly to depositional environment as well as to pollen production. The generally lower standard deviations for the mean percents of total basal area are an indication that the mixing process, either in the river or in the atmosphere or in both, smoothes out the variability in the pollen distributions compared to the distributions of the trees.

Next the spatial variations in the total number of pollen grains per gram dry sediment and percents of the tree pollen were compared with the spatial variation in total basal area and percents basal area of the respective trees to observe whether similar gradients corresponded in the tree types and their respective pollen types. A gradient is considered a true gradient if both the t-value and the correlation coefficient are significant. Table 11 presents results from regressions of total number of pollen grains per gram dry sediment and percents of total pollen for the tree species present in the channel samples. There is no significant correlation between distance downstream and total number of pollen grains per gram dry sediment or on percents of beech, ironwood-hazelnut, birch, hickory, blackgum, oak, walnut, red cedar, dogwood, holly and cherry, while there is a significant correlation for percents of elm, ash, sycamore, sweet gum, maple, red maple and pine. The t-values for the latter types show that distance does have an effect on the percent of total pollen (the slope of the lines is different from 0). According to the slopes of the regression lines, the distance effect is slightly negative (percent of total pollen decreases with distance downstream) for elm, ash, sycamore, maple and red maple, slightly positive (percent of total pollen increases with distance downstream) for sweet gum, and relatively much more pronounced in the positive direction for pine.

Table 12 shows the results from regressions of mean total basal area and percents of total basal area of each tree type for each latitudinal section on longitudinal distance from north to south, and it shows the regressions of mean total basal area and percent of total basal area of each tree type for each longitudinal section on latitudinal distance from west to east. These mean values are presented with their standard deviations and numbers of observations in Table 13. There is no observable trend, i.e., significant t-value and correlation coefficient, in the vegetation in either the latitudinal or longitudinal direction except for pine which increases relatively greatly from north to south, sweet gum which increases slightly from north to south, hickory which decreases slightly from west to east, and red cedar which decreases from west to east and increases from north to south, in both cases very slightly. The southward increase of pine and sweet gum in the vegetation is observed also in the pollen distributions (Figures 24 and 25) but the eastward decrease in hickory and red cedar is not present in the pollen distributions because the gradients in the vegetation probably are very slight. The differences that appear in the pollen assemblages of all other types which show no vegetational gradient must be attributed to the differential effect of transport and depositional processes.

TABLE 11. REGRESSION OF PERCENT OF TOTAL POLLEN (y) IN THE SURFACE SEDIMENTS (n=20) ON DISTANCE DOWNSTREAM IN NAUTICAL MILES (x)

Total pollen grains per gram dry sediment (%)	Regression Equation	r	t-value
	y = 61426.8 + 222.8 x	0.182	1.45
Acer	y = 1.14 - 0.013 x	-0.473*	- 3.55†
Acer rubrum	y = 0.43 - 0.005 x	-0.564‡	- 5.23†
Betula	y = 3.79 - 0.002 x	-0.223	- 0.30
Carya	y = 2.45 + 0.001 x	0.017	0.19
Carpinus - Corylus	y = 0.92 + 0.004 x	0.151	1.17
Cornus	y = 0.05 + 0.00006 x	0.014	0.11
Fagus	y = 0.29 + 0.001 x	0.103	0.63
Fraxinus	y = 2.97 - 0.034 x	-0.608‡	- 6.06†
Ilex	y = 0.05 + 0.001 x	0.245	1.77
Juglans	y = 0.905 - 0.002 x	-0.198	1.28
Juniperus	y = 0.26 + 0.004 x	-0.255	2.06
Liquidambar	y = 0.392 + 0.015 x	0.527*	4.98†
Nyssa	y = 0.16 + 0.0004 x	0.042	0.37
Pinus	y = 9.16 + 0.22 x	0.844‡	12.32†
Platanus	y = 5.01 - 0.05 x	-0.713‡	- 7.98†
Prunus	y = 0.08 + 0.0008 x	0.092	0.76
Quercus	y = 24.10 + 0.05 x	0.324	2.67§
Ulmus	y = 3.62 - 0.039 x	-0.800‡	-10.23†

*correlation coefficient is significant at 0.05 level

†t-value is significant at 0.01 level indicating that the slope of the regression line is significantly different from zero

‡correlation coefficient is significant at 0.01 level

§t-value is significant at 0.05 level

TABLE 12. REGRESSION OF MEAN BASAL AREAS IN LATITUDINAL AND LONGITUDINAL SECTION (y) IN THE VEGETATION ON DISTANCE OF SECTION FROM NORTH TO SOUTH OR WEST TO EAST IN MILES (x)

Total basal area (%) (cm^3)	Regression equation of mean basal areas in longitudinal sections on distance from west to east (n=9)	r	t-value	Regression equation of mean basal areas in latitudinal sections on distance from north to south (n=10)	r	t-value
	y = 11078.4 + 1.7 x	0.018	0.09	y = 10928.0 + 9.3 x	0.176	-1.68
Acer	y = 0.95 - 0.008 x	-0.100	-0.50	y = 1.83 - 0.026 x	-0.392	-2.23
Acer rubrum	y = 4.46 + 0.023 x	0.153	0.76	y = 5.53 - 0.014 x	-0.16	-0.60
Betula	y = 2.26 - 0.007 x	-0.069	-0.33	y = 1.91 + 0.029 x	0.191	1.04
Carya	y = 7.56 - 0.152 x	-6.36*	-4.03†	y = 1.88 + 0.002 x	0.037	0.19
Carpinus-Corylus	y = 0.118 + 0.022 x	0.490	2.76‡	y = 0.38 + 0.012 x	0.272	1.48
Cornus	y = 0.56 + 0.009 x	0.310	1.54	y = 1.39 - 0.012 x	-0.462	-2.79‡
Fagus	y = 2.43 + 0.012 x	0.093	0.46	y = 4.30 - 0.035 x	-0.291	-1.61
Fraxinus	y = 0.73 - 0.0002 x	-0.005	-0.02	y = 1.45 - 0.014 x	-0.312	-1.68
Ilex	y = 3.87 - 0.042 x	-0.512	-2.91‡	y = 0.81 + 0.028 x	0.454	2.64‡
Juglans	y = 0.004 + 0.001 x	0.274	0.08	y = 0.02 + 0.0002 x	0.058	-0.02
Juniperus	y = 0.57 - 0.010 x	-0.599*	-3.64†	y = 0.004 + 0.003 x	0.547*	-3.24‡
Liquidambar	y = 7.54 + 0.024 x	0.100	0.49	y = 5.39 + 0.089 x	0.572*	3.68†
Nyssa	y = 6.35 - 0.063 x	-0.266	-1.34	y = 3.38 + 0.020 x	0.246	1.37
Pinus	y = 6.12 + 0.303 x	0.569	3.37‡	y = 2.53 + 0.378 x	0.732§	5.64†
Platanus	y = 1.15 - 0.011 x	-0.160	0.83	y = 0.63 + 0.010 x	0.207	1.08
Prunus	y = 0.56 - 0.004 x	-0.188	-0.90	y = 0.34 + 0.002 x	0.106	0.60
Quercus	y = 40.58 - 0.068 x	-0.114	-0.01	y = 35.61 - 0.051 x	-0.169	-0.90
Ulmus	y = 0.438 + 0.026 x	0.262	1.32	y = 1.52 - 0.009 x	-0.153	0.83

*correlation coefficient is significant at 0.10 level

†t-value is significant at 0.01 level, indicating that the slope of the line is different from zero

‡t-value is significant at 0.05 level

§correlation coefficient is significant at 0.05 level

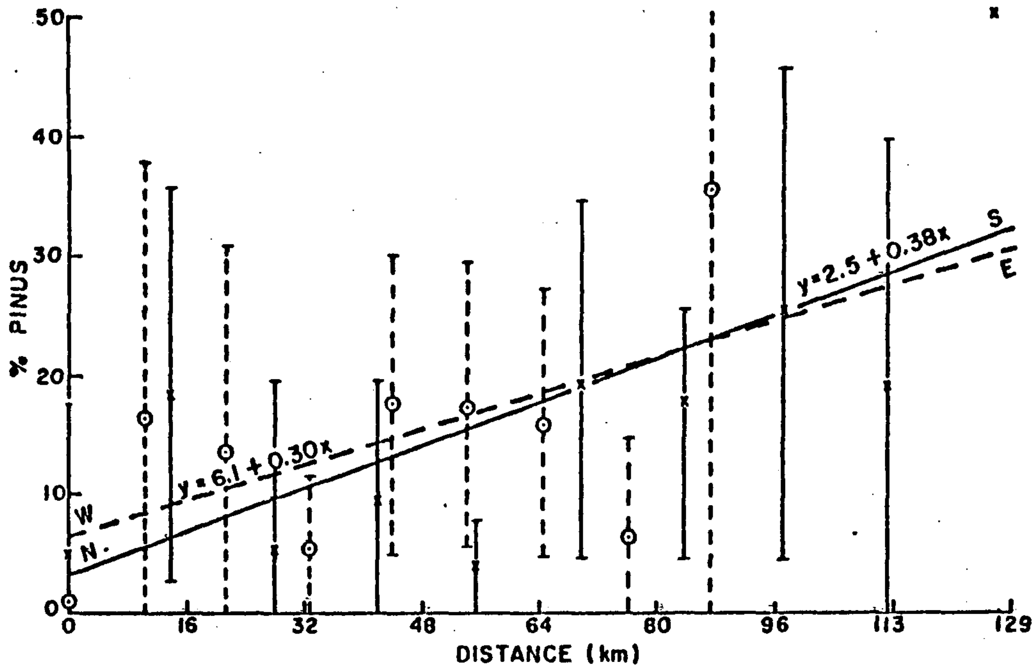
TABLE 13. MEAN TOTAL BASAL AREAS AND MEAN PERCENT BASAL AREAS IN THE VEGETATION

	NORTH				BY LATITUDINAL SECTION					SOUTH
Quad Nos. in each latitudinal section	1-3	4-8	9-11	12-16	17-21	22-27	28-35	36-39	40-42	43
Distance of section north to south in miles	0	8.7	17.4	26.1	34.8	43.5	52.2	60.9	69.6	78.3
No. of plots	5	18	12	16	16	24	20	12	8	1
Mean total basal area (cm^2)	8172.8	12399.9	11125.5	12415.8	12787.4	11881.4	10694.4	11407.5	9988.3	12051.0
S. D.	2657.2	4075.2	5214.2	4153.7	5531.8	3074.5	3605.9	2653.4	2537.2	---
Mean % *Acer*	-0-	4.9	-0-	-0-	3.2	-0-	-0-	-0-	-0-	-0-
S. D.	-0-	20.8	-0-	-0-	12.5	-0-	-0-	-0-	-0-	---
Mean % *Acer rubrum*	2.8	2.6	10.6	1.9	7.6	6.0	7.9	6.3	4.0	-0-
S. D.	2.2	5.4	18.3	3.4	8.4	9.7	13.7	7.7	5.3	---
Mean % *Betula*	-0-	2.3	5.8	0.6	5.2	3.4	-0-	0.6	12.4	-0-
S. D.	-0-	6.9	17.8	2.3	18.5	11.1	-0-	2.0	25.2	---
Mean % *Carya*	0.4	1.0	1.8	4.9	1.2	2.3	3.6	2.7	1.7	-0-
S. D.	0.9	2.0	3.3	10.7	2.5	4.2	6.0	5.6	4.5	---
Mean % *Carpinus-Corylus*	-0-	0.1	0.2	0.3	2.9	0.4	0.9	3.1	0.6	-0-
S. D.	-0-	0.2	0.6	0.7	9.2	1.2	2.0	7.0	1.5	---
Mean % *Cornus*	1.6	0.7	1.5	0.4	0.4	1.0	2.0	1.2	-0-	-0-
S. D.	3.6	1.1	2.0	1.6	0.9	1.7	3.3	2.0	-0-	---
Mean % *Fagus*	-0-	1.6	4.5	9.9	4.9	4.8	2.4	1.3	-0-	-0-
S. D.	-0-	6.1	15.3	16.7	10.7	9.1	5.5	2.9	-0-	---
Mean % *Fraxinus*	-0-	0.1	2.4	3.0	2.3	-0-	1.1	-0-	-0-	-0-
S. D.	-0-	0.2	6.3	8.0	6.5	0.2	3.7	-0-	-0-	---
Mean % *Ilex*	1.4	0.6	0.8	0.1	2.4	2.6	2.7	3.6	5.1	-0-
S. D.	2.2	1.5	1.4	0.5	6.3	6.9	3.4	3.3	4.2	---
Mean % *Juglans*	-0-	-0-	-0-	-0-	-0-	0.3	-0-	-0-	-0-	-0-
S. D.	-0-	-0-	-0-	-0-	-0-	1.2	-0-	-0-	-0-	---
Mean % *Juniperus*	-0-	-0-	-0-	-0-	0.1	0.3	0.3	0.2	0.4	-0-
S. D.	-0-	-0-	-0-	-0-	0.3	0.9	0.6	0.4	1.1	---
Mean % *Liquidambar*	2.0	8.4	4.2	12.7	8.8	7.1	9.9	13.6	14.9	7.0
S. D.	4.5	15.1	5.9	17.2	13.0	13.5	13.8	17.5	14.8	---
Mean % *Nyssa*	5.8	2.5	3.0	4.5	4.4	2.1	2.1	4.4	3.1	9.0
S. D.	11.3	3.4	4.2	8.5	8.2	3.0	3.5	4.5	3.6	---
Mean % *Pinus*	5.0	18.7	5.9	9.3	3.7	19.2	17.6	25.2	18.9	50.0
S. D.	8.3	27.3	17.8	16.0	7.5	30.8	25.0	28.1	23.1	---
Mean % *Platnus*	-0-	0.2	0.2	0.8	3.8	0.4	-0-	2.7	1.7	-0-
S. D.	-0-	0.7	2.3	3.3	8.5	1.8	-0-	5.9	5.0	---
Mean % *Prunus*	-0-	0.9	0.3	-0-	-0-	0.8	1.2	0.1	0.8	-0-
S. D.	-0-	3.3	0.6	-0-	-0-	2.7	4.1	0.3	1.4	---
Mean % *Quercus*	47.7	43.4	19.6	26.5	28.1	33.4	33.3	33.4	38.7	32.0
S. D.	46.5	32.3	32.1	28.7	25.6	29.9	26.6	22.0	32.4	---
Mean % *Ulmus*	-0-	0.2	0.8	4.8	1.7	2.6	0.9	0.7	-0-	-0-
S. D.	-0-	0.7	2.3	13.0	3.7	10.8	3.6	2.3	-0-	---

(Continued)

TABLE 13 (Continued)

	WEST			BY LONGITUDINAL SECTION					EAST
Quad Nos. in each longitudinal section	28	22,29	12,17, 23,30	4,13,18 24,31	5,9,14,19 25,32,36	1,6,10, 15,20,26, 33,37	2,7,11, 16,21,27, 34,38,40	3,8,35, 39,41	42,43
Distance of section west to east in miles	0	6.8	13.6	20.4	27.2	34.0	40.8	47.6	54.4
Number of Plots	1	6	10	16	26	29	31	11	2
Mean total basal area (cm²)	7492.0	12858.0	12924.9	10838.1	12905.4	11421.4	11106.6	10028.6	10553.5
S. D.	---	2755.3	2991.9	4559.6	5118.7	3890.2	3240.3	3083.5	2117.8
Mean % *Acer*	-0-	-0-	-0-	3.2	3.4	-0-	-0-	-0-	-0-
S. D.	---	-0-	-0-	12.5	17.5	-0-	-0-	-0-	-0-
Mean % *Acer rubrum*	1.0	2.3	7.7	9.8	5.0	6.7	4.1	6.2	3.0
S. D.	---	2.9	9.0	16.5	16.1	12.6	6.6	8.6	4.2
Mean % *Betula*	-0-	-0-	4.2	4.6	3.8	2.5	2.9	0.6	-0-
S. D.	---	-0-	12.3	11.7	14.6	11.6	12.6	2.1	-0-
Mean % *Carya*	15.0	2.2	1.6	3.7	2.4	2.3	1.8	1.9	-0-
S. D.	---	5.3	4.1	9.8	4.5	5.0	3.9	3.7	-0-
Mean % *Carpinus-Corylus*	-0-	0.2	0.2	0.8	0.5	1.3	0.8	2.6	-0-
S. D.	---	0.4	0.6	1.6	1.3	6.9	3.0	6.3	-0-
Mean % *Cornus*	-0-	0.8	0.8	0.7	1.2	0.8	1.3	1.7	-0-
S. D.	---	2.0	1.1	1.6	1.8	1.5	2.7	2.8	-0-
Mean % *Fagus*	-0-	0.2	3.9	6.0	3.0	6.1	3.6	2.0	-0-
S. D.	---	0.4	10.8	14.5	7.9	12.6	9.1	6.6	-0-
Mean % *Fraxinus*	-0-	0.8	0.1	2.4	0.4	0.7	2.1	-0-	-0-
S. D.	---	2.0	0.3	6.6	1.6	3.9	6.5	-0-	-0-
Mean % *Ilex*	6.0	2.5	3.9	1.9	2.0	0.5	2.3	3.0	2.5
S. D.	---	2.9	7.7	6.8	4.5	1.2	3.3	4.3	3.5
Mean % *Juglans*	-0-	-0-	-0-	-0-	-0-	-0-	0.2	-0-	-0-
S. D.	---	-0-	-0-	-0-	-0-	-0-	1.1	-0-	-0-
Mean % *Juniperus*	1.0	0.2	0.4	0.1	0.2	0.5	-0-	0.3	-0-
S. D.	-0-	0.7	0.8	0.3	0.8	0.5	-0-	0.9	-0-
Mean % *Liquidambar*	-0-	11.0	14.1	5.8	10.1	8.3	8.2	12.7	3.5
S. D.	---	19.7	11.9	8.0	14.5	17.4	11.2	16.9	5.0
Mean % *Nyssa*	1.5	1.8	2.1	1.8	5.3	3.1	3.3	1.3	8.0
S. D.	---	2.1	3.1	2.0	8.1	4.3	6.4	1.5	1.4
Mean % *Pinus*	1.0	16.5	13.7	5.7	17.3	17.4	15.9	6.4	35.5
S. D.	---	16.6	25.1	9.3	26.9	27.4	25.9	9.9	20.5
Mean % *Platanus*	0.0	-0-	3.3	2.0	0.1	0.5	1.9	-0-	-0-
S. D.	---	-0-	2.8	8.6	0.6	1.9	5.0	-0-	-0-
Mean % *Prunus*	-0-	1.3	0.1	0.5	0.5	0.6	0.7	0.3	-0-
S. D.	---	3.3	0.3	1.4	2.2	2.6	3.3	0.9	-0-
Mean % *Quercus*	58.0	45.0	29.0	28.3	29.0	35.3	28.9	48.2	47.0
S. D.	---	35.1	29.2	30.8	26.2	29.2	30.1	30.2	21.2
Mean % *Ulmus*	-0-	-0-	0.2	-0-	3.8	1.6	4.7	-0-	-0-
S. D.	---	-0-	0.6	-0-	6.9	5.5	13.4	-0-	-0-



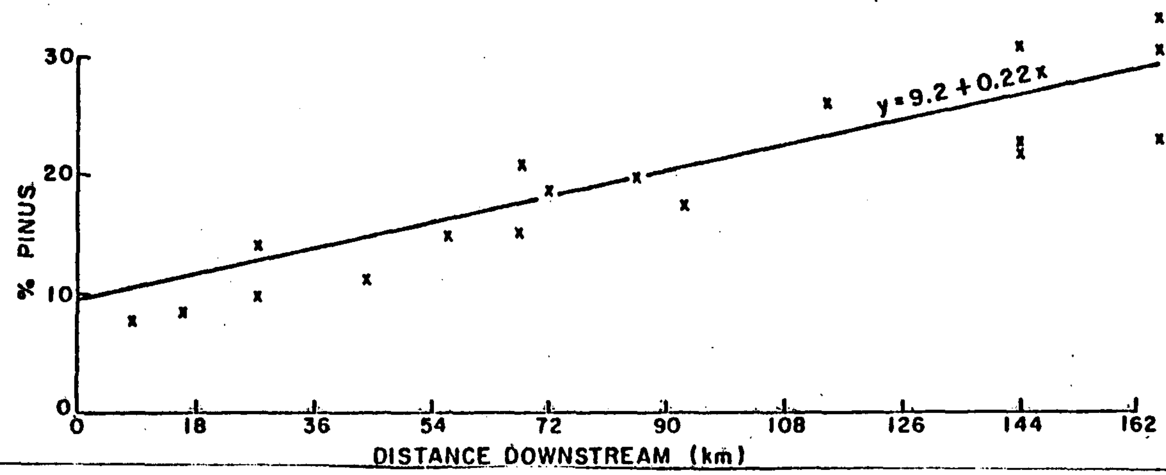
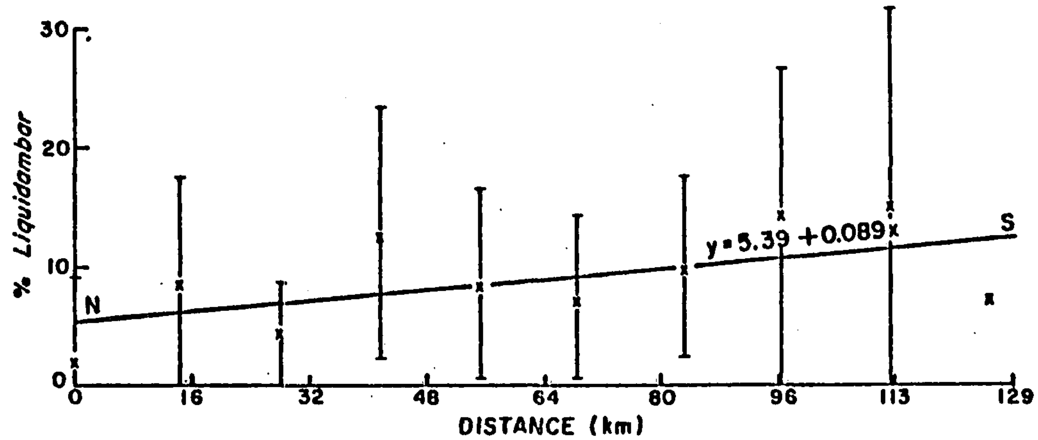


Figure 24a. Percent pine of total basal area in vegetation versus latitudinal and longitudinal distance with 95 percent confidence intervals.

Figure 24b. Percent pine of total pollen in channel samples versus distance downstream.



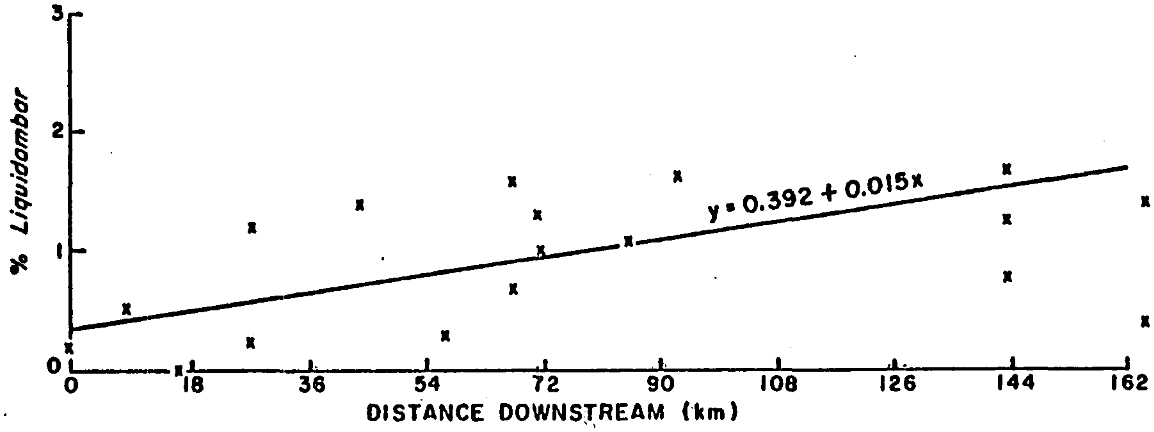


Figure 25a. Percent sweet gum of total basal area in vegetation versus latitudinal and longitudinal distance with 95 percent confidence intervals. (No significant difference exists for percent sweet gum versus longitudinal distance.)

Figure 25b. Percent sweet gum of total pollen in channel samples versus distance downstream.

Effect of Transport on Pollen Distributions

The distance a pollen grain is transported in an estuary is dependent upon the depth of the water, the degree of turbulence in the water column, and the settling properties of the pollen once it enters the water. For a river such as the Potomac, it is assumed that turbulence immerses the pollen completely within a few meters of downstream transport. Once immersed, pollen will behave like similar particles with small Reynolds numbers and falling within the range of Stokes law of resistance. Some differentiation is to be expected because size and specific gravity differ among pollen types, not all grains are spherical and size and shape can change with immersion (Brush and Brush 1972). Based upon the behavior of small particles in turbulent flow (McNown et al. 1951, Brush 1965) and data obtained from a laboratory study of pollen transport in a small sediment-laden flume (Brush and Brush 1972), some interpretations were made regarding the effect of transport on pollen distributions in the Potomac surface sediments.

The effects of transport were identified by the selective deposition of pollen types in channel and nonchannel sediments and by the value of the correlation coefficient for percent of total pollen versus distance downstream. A high correlation coefficient indicates less scatter in the data than a low regression coefficient. A lot of scatter means that very little dispersion of the pollen has occurred and the pollen is deposited close to its source or that differential deposition is operating after the pollen becomes mixed in the water column resulting in a secondary uneven distribution.

Correlation coefficients for percent of total basal area with latitudinal and longitudinal distance are low for all species of trees indicating that distributions of the source vegetation are highly uneven or patchy. This is an accurate description of tree distributions because individuals of a species occur most commonly as stands or in more or less discrete clumps. Therefore, pollen distributions with low correlation coefficients are reflecting the local patchiness of the tree distributions, whereas those with high correlation coefficients have had the vegetational patchiness erased from their distributions by dispersion.

Five types of transport behavior are recognized in the distributions of pollen described here:

1. Hickory (40-45 μ), beech (40-45 μ), cherry (25-30 μ) and holly (25-30 μ) occur more frequently in the nonchannel samples and show insignificant correlation coefficients. Once introduced into the river, it appears that they settle quickly and are deposited in shallower water. There is no information available on the settling velocities of these grains.

2. Oak (25-30 μ), black gum (30-35 μ), walnut (35-40 μ), dogwood (35-40 μ) and red cedar (25-30 μ) occur nonselectively in channel and nonchannel samples and show a lot of scatter. They are not transported far in the water before being deposited. Atmospheric transport may ensure their even distribution across the channel. Once in the water they settle rapidly. Oak has a specific gravity of 1.2 which does not indicate a high settling velocity relative to many other pollen types. Observations for oak are in

agreement with laboratory results where only 2 percent of the oak pollen load remained in suspension 15 minutes after entry into the water column (Brush and Brush 1972). The behavior of oak in the experimental study contrasted strongly with other pollen types which remained in suspension in much greater numbers and therefore for a longer period of time. The settling properties of red cedar pollen erase from the pollen distributions the very slight gradients that appear in the distributions of the trees.

3. Ironwood-hazelnut, with an average size of 30 μ, were selectively deposited in the channel sediments where the water is deeper. However, the data contain a lot of scatter indicating that although deposition occurred in the deeper water, the pollen grains did not remain in suspension very long and are probably deposited close to their entry. In the previously mentioned laboratory study, hazelnut occurred in fairly large numbers in the bed although not nearly approaching the deposition rate of oak.

4. Maple (40-50 μ), red maple (49 μ), ash (38-41 μ), elm (37 μ), and sycamore (19-22 μ) are deposited nonselectively in channel and nonchannel sediments. They show less scatter than the previously discussed grains indicating that they are deposited evenly and may be transported a greater distance. They decrease in frequency in the downstream sediments because they probably remain suspended in this part of the river where the water is deeper and more turbulent.

5. The pollen type most affected by transport is that of birch (30 μ). It occurs in both channel and nonchannel samples and shows virtually no scatter indicating that it remains in suspension for a long period of time and is totally dispersed before being deposited. This observation agrees with the previous laboratory observation where 71 percent of the birch pollen load remained in suspension 15 minutes after entry into the water column. In that study it was observed also that the size and shape of birch changed with immersion in such a way as to decrease its settling rate.

It is inferred from these results that transport processes disperse the pollen to a greater or lesser degree depending upon the physical properties of the individual grains. Thus, transport and selective deposition of pollen serve to erase, for some tree types more than for others, some of the patchy characteristics of tree distributions without altering the pollen assemblage's representation of the regional vegetation.

Conclusions

1. Adequate amounts of pollen for compiling pollen assemblages are obtained more frequently in channel as opposed to nonchannel sediments in the tidal Potomac River. The results are reproducible at any one location. For an overall view of the pollen assemblages in the tidal Potomac, it is necessary to obtain only two samples, one located in the upper region of the tidal river and the other close to the mouth.

2. The pollen in the channel surface sediments are, for the most part, representative of the adjacent vegetation. All types abundant in the vegetation appear in the pollen assemblage except tulip poplar. In spite of

differential productivity and transport for different pollen types, there is a fairly good correspondence between percents of total basal area and percents of total pollen with a few types being under- or overrepresented in the pollen. The southward increase in pine and sweetgum in the vegetation is reflected in the pollen assemblages of the surface sediments, while the westward decrease of hickory and the westward decrease and southward increase of red cedar are too slight to be recorded in the pollen distributions.

3. Transport processes in the atmosphere and water erase some of the localized patchy distributions of the vegetation types from the pollen distributions. The degree to which this occurs is related to the physical characteristics of each type of pollen grain.

4. Since the estuarine processes reduce local noise in the pollen distributions without obliterating representation of regional gradients in the vegetation, this depositional environment is considered useful for stratigraphic work.

VERTICAL DISTRIBUTIONS OF POLLEN IN ESTUARINE SEDIMENTS

With respect to the dating of stratigraphic horizons for determining sedimentation rates, this study concentrated on establishing rates in the Upper Chesapeake Bay. The number of horizons that can be dated from a core depend upon the time interval covered by the core and the number of land use and vegetation changes during that time interval that are of a sufficient scale both in area affected and in intensity to be reflected by changes in pollen assemblages. As indicated earlier, localized changes are likely to be masked by the regional condition.

Two cores from the Susquehanna Flats (SF-2 and SF-3) were analyzed and two (FB-I and FB-II) in detail and one (FB-III) partially from Furnace Bay (see Figures 2 and 3 for locations of cores). The two cores from Susquehanna Flats contained very low concentrations of pollen; consequently, these analyses were not continued for this study. It appears from the counts made that by concentrating the pollen extracted from the samples (see Quality Assurance Report), it may be possible to obtain sufficient data to compile vertical profiles showing changes in the assemblages. This investigation is proceeding. The cores from Furnace Bay contained well-preserved pollen in sufficient numbers to provide sedimentation rates for different time intervals.

In cores FB-I and FB-II, all pollen types were identified; Figures 26 and 27 have been plotted with only those types that provide information regarding sedimentation rates. In core FB-III, only the oak and ragweed pollen were identified in order to identify the agricultural horizons.

Furnace Bay Core Number I (Figure 26)--

This core is 96 cm long and consists of silt and clay throughout. The top 79 cm are dark grey while the zone from 79 to 92 cm is a light brownish grey. Darker colored bands occur at 6 to 7 cm, and brown bands were observed at 22 to 23 cm, 30 to 31 cm and 39 to 40 cm. The top 8 cm has a higher water content than the remainder of the core.

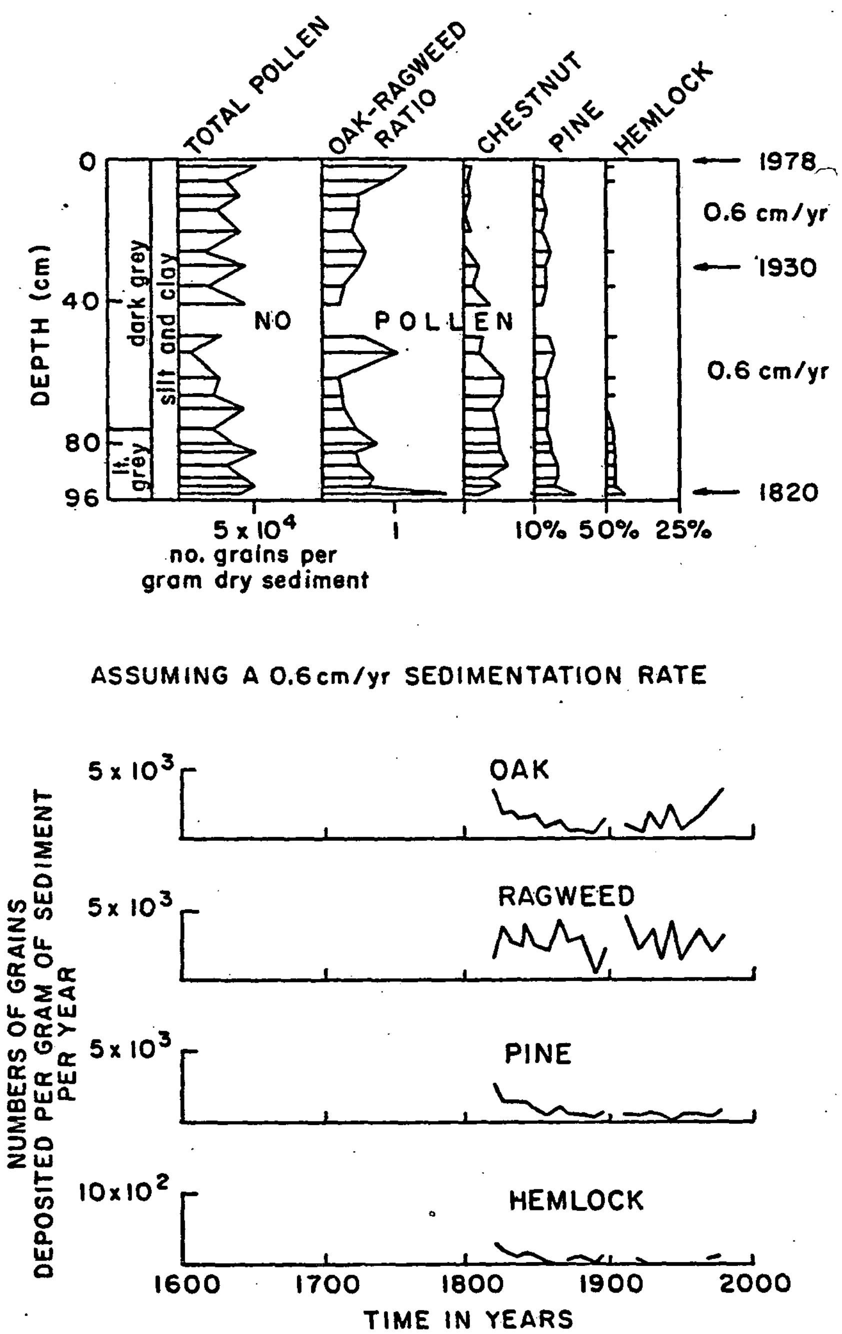


Figure 26. Stratigraphic pollen profile of Core I from Furnace Bay and the flux of pollen of oak, ragweed, pine and hemlock.

Total pollen per gram dry sediment fluctuates considerably between levels. Except for a zone of no pollen between 40 and 50 cm, pollen concentrations are fairly high throughout.

The oak-ragweed ratio, an indicator of clearing of forests for agriculture, remains less than 1 throughout the core except for the bottom 2 cm where it reaches 1.8. This large increase in oak pollen indicates that at the time the area was mostly forested with some local clearing. Historical records show that at Furnace Bay the area of land cleared by 1840 remained constant to 1960 (see Section 3). There are no records of area of land cleared in 1820, but there are records indicating that agriculture was well established by 1820. Since there is only one significant decrease in the oak-ragweed ratio in the core, it is assumed it reflects the time of well-established agriculture and that the area of land cleared in 1820 was essentially the same as in 1840. Therefore, an 1820 date has been assigned to the 94 cm level where the oak-ragweed ratio changes from 1.8 to 0.7.

Although chestnut pollen is never entirely eliminated, it decreases rather dramatically at 30 cm. The chestnut blight began to infect trees by 1910 and by 1930, most of the chestnut trees were dead (Anderson 1974). In this core, a 1930 date has been assigned to the 30 cm level where the chestnut decreases. It is believed that the decrease represents the demise of the species and the reason the pollen persists throughout is probably due to some mixing of sediments. Fluctuations in total pollen lead to surmising that mixing may have occurred, but even if this were the case, it is not sufficient to obliterate major changes in the pollen distributions. Based upon these dated horizons, sedimentation rates average 0.6 cm/yr throughout the core. Assuming a 0.6 cm/yr rate of sedimentation, the influx (numbers of grains deposited per gram of sediment per year) of the major pollen types in the core, viz., oak, ragweed, pine, and hemlock, have been plotted.

Furnace Bay Core Number II (Figure 27)--

This core, 123 cm long, is macroscopically very similar to core FB-I. The top 84 cm are an homogenized dark grey silt and clay which becomes a light brownish grey from 84 to 131 cm. Brown bands occur at 23 to 24 cm and 33 to 34 cm.

Total pollen does not fluctuate nearly as much as in core FB-I. Total pollen per gram dry sediment are almost twice as high at the bottom of the core as at any other level. Total numbers decrease dramatically toward the center of the core with a zone of no pollen from 56 to 64 cm.

The oak-ragweed ratio of 18 at the bottom of the core indicates that ragweed essentially is absent in this part of the core which extends down to 92 cm. This zone represents presettlement time. At 92 cm, the oak-ragweed ratio changes to 1.8 and decreases to well below 1 at 84 cm. The first decrease was interpreted in the ratio to reflect initial settlement and clearing, which occurred at about 1790 in the area (see Section 3). The second decrease at 84 cm is identical to the decrease in core FB-I at 94 cm, which is interpreted as representing the time of well-established agriculture and to which a date of 1820 was assigned.

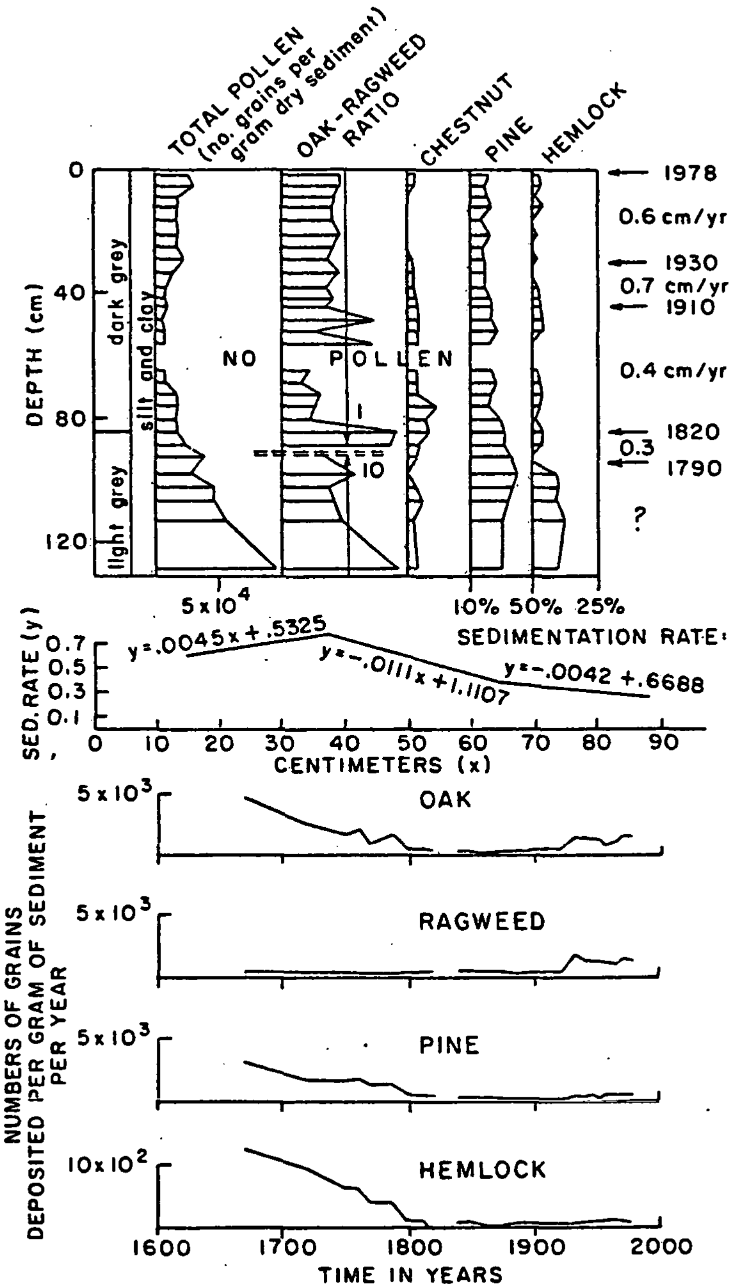


Figure 27. Stratigraphic pollen profile of Core II from Furnace Bay and the flux of pollen of oak, ragweed, pine and hemlock.

The chestnut profile fluctuates considerably. The low numbers in the bottom of the core (during presettlement time) probably are related to forest density. Chestnut flowers in late summer when trees are in full leaf. It is possible that in dense forests, prior to clearing, much of the chestnut pollen is filtered out before reaching a depositional basin (see Tauber 1965 for a discussion of factors affecting the atmospheric dispersion of pollen). After 1820, the numbers of chestnut pollen increase and then decrease in the center of the core, but this decrease is coincident with very low concentrations of total pollen. At 44 cm, the numbers of chestnut decrease by one-half; a 1910 date to this horizon has been assigned, which is believed to represent the initial impact of the blight. At approximately 30 cm, chestnut pollen is no longer present; a 1930 date has been assigned, the time when the trees were no longer existent, to this level. Chestnut pollen in the top 4 cm is produced by the oriental chestnuts which were planted throughout the eastern United States in the early 1940's.

Based upon these dates, sedimentation rates average 0.5 cm/yr for the entire core, with average rates of 0.3 cm/yr from 1790 to 1820, 0.4 cm/yr from 1820-1910, 0.7 cm/yr from 1910 to 1930, and 0.6 cm/yr from 1930 to the present.

Because changes in the sedimentation rates in the real world probably are more gradual than indicated by the average values, it was decided to approximate the changes. To do this, it was assumed that the change was linear and that the rate at the midpoint of the interval was the average rate. Accordingly, the midpoints of each interval were plotted against the sedimentation rate for that interval. These points were connected by lines the equations of which are used to obtain the intermediate sedimentation rates. For core levels below the last dated horizon and above the first dated horizon, it was assumed that the sedimentation rate from the previous level remains constant through this section.

Pollen, seed and diatom influx values (i.e., the numbers of pollen, seeds, and diatoms deposited per gram or per cm^2 of sediment per year) are calculated by dividing the total counts at each level by the number of years represented by each sample analyzed.

Based upon the sedimentation rates for core FB-II (Figure 27), the pollen influx shows clearly that the major tree species, oak, pine and hemlock all decrease dramatically with the advent and establishment of agriculture. The influx of pine and hemlock is particularly interesting because it does not reflect the presence of abundant pine and hemlock stands in the Appalachian Plateau of Pennsylvania, approximately 100 km northwest of Furnace Bay, which were extensive as late as 1840 for pine and 1880 for hemlock (see Section 3). Although changes in the vegetation of the Piedmont section of the Susquehanna watershed caused by agriculture are documented in the pollen assemblages from Furnace Bay cores, changes in the vegetation of the Appalachian section of the watershed are apparently not reflected because they are too distant. The large amounts of pollen of hemlock and pine that are present in the bottom part of both cores must have originated from trees growing in the Piedmont which were cut at the time land was cleared for agriculture. If the pollen were derived from Appalachian vegetation, it should be present in sediments deposited after 1820 because the forests in the Appalachian Plateau were not cleared for agriculture. Apparently pollen from the upper watershed was not transported into this area during any time interval. This is in agreement with the observations made on pollen distributions in the tidal Potomac surface sediments where pollen of trees restricted to the Appalachian province today are not present in surface sediments approximately 50 km downstream from the source.

Furnace Bay Core Number III--

Only oak and ragweed pollen from this core were counted and therefore we have identified only the agricultural horizon. This occurs at 93 cm based upon the change in the oak-ragweed ratio. A date of 1820 was assigned to this level. Based upon this date, the average sedimentation rate from 1820 to the present is 0.6 cm/yr.

Other Tributaries--

Table 14 summarizes all of the dates that have been assigned to different sedimentary horizons in a number of tributaries based upon pollen analyses. The rates average approximately 0.6 cm/yr from all cores, but the range within a core is as great or greater than the range between cores from the same tributary, or between cores from different tributaries. For example, in one core from Back River rates range from 0.3 cm/yr to 1.9 cm/yr. Rates appear higher during the agricultural periods for some tributaries with large drainage areas (e.g., Back River) than for some with smaller drainage areas (e.g., Middle River), but the hydrodynamics of the tributaries is also important. For example, the sedimentation rate in the middle of Back River is much greater than at the mouth because Back River acts as a depositional sink (Han 1972).

Conclusions

1. The clearing of land for agriculture and the decrease and demise of chestnut are the two major events that are reflected in pollen assemblages from estuarine sediments. Dates of 1910 and 1930 are assigned to the chestnut horizons and anywhere from 1790 to 1890 to the agricultural horizon depending upon the specific location. Rapid urbanization where it has occurred is reflected by increased concentrations of pollen in the sediments. In some instances, farm abandonment can be detected by an increase in the ratio of oak pollen to ragweed pollen.

2. Sedimentation rates average approximately 0.6 cm/yr in all of the cores studied but vary from less than 0.2 cm/yr to approximately 2 cm/yr.

3. The data gathered so far suggest the influence of land use on rates of sedimentation is influenced by drainage area and the morphometry of the rivers. However, specific relationships will not be studied until sedimentation rates have been obtained for more tributaries.

TABLE 14. SUMMARY OF SEDIMENTATION RATES BASED ON PALYNOLOGICAL INDICATORS THUS FAR OBTAINED FOR CHESAPEAKE BAY AND TRIBUTARIES

Location*	Core	Dated Horizons	Stratigraphic Indicator for Date	Historical Basis for Date	Sedimentation Rate
Susquehanna Flats†	3	0 cm - 1978	year core was collected		1.0 cm/yr
		98 cm - 1880	presence of abundant coal particles	anthracite industry in watershed well developed	
Furnace Bay†	III	0 cm - 1978	year core was collected		0.6 cm/yr
		93 cm - 1820	large increase in ragweed pollen	agriculture well established at ~ 1820	
Furnace Bay†	I	0 cm - 1978	year core was collected		0.6 cm/yr
		30 cm - 1930	absence of chestnut pollen	by 1930, all chestnut trees eliminated by blight	
Furnace Bay†	II	0 cm - 1978	year core was collected		0.6 cm/yr
		30 cm - 1930	absence of chestnut pollen	by 1930, chestnut trees eliminated by blight	0.7 cm/yr
		44 cm - 1910	decrease in chestnut pollen	at ~ 1910, chestnut blight attacked trees	0.4 cm/yr
		84 cm - 1820	large increase in ragweed pollen	agriculture well established	0.3 cm/yr
		92 cm - 1790	moderate increase in ragweed pollen and decrease in tree pollen	modest agricultural development	
Middle River	M-2	0 cm - 1974	year core was collected		0.3 cm/yr
		4 cm - 1960	increase in total pollen concentration	large scale urban development	0.4 cm/yr
		34 cm - 1980	large increase in ragweed pollen	1890 - time of maximum agriculture in Balto. Co.	
Back River	T	0 cm - 1974	year core was collected		0.8 cm/yr
		38 cm - 1930	absence of chestnut pollen	chestnut blight eliminated chestnut trees	(0.4 cm/yr)
		(12-20 cm deposited in one year)		pollen concentration greatly reduced but preservation excellent	
		70 cm - 1910	decrease in chestnut pollen	beginning of chestnut blight	1.7 cm/yr
Back River	B	0 cm - 1974	year core was collected		0.6 cm/yr
		8 cm - 1960	increase in total pollen concentration	large scale urban development	0.3 cm/yr
		18 cm - 1930	absence of chestnut pollen	chestnut trees eliminated by blight	1.6 cm/yr
		50 cm - 1910	decrease in chestnut pollen	beginning of chestnut blight	1.9 cm/yr
		88 cm - 1890	large increase in ragweed pollen	maximum agriculture in Baltimore County	
Back River	R	0 cm - 1974	year core was collected		0.2 cm/yr
		20 cm - 1890	large increase in ragweed pollen	maximum agriculture in Baltimore County	
Potomac River	1	0 cm - 1977	year core was collected		1.0 cm/yr
		66 cm - 1910	decrease in ragweed pollen	some farm abandonment	
Potomac River	4	0 cm - 1977	year core was collected		0.4 cm/yr
		24 cm - 1910	decrease in ragweed pollen	some farm abandonment	0.7 cm/yr
		74 cm - 1840	large increase in ragweed pollen	agriculture well established	
Potomac River	3	0 cm - 1977	year core was collected		0.5 cm/yr
		30 cm - 1910	decrease in ragweed pollen	some farm abandonment	
Chesapeake Bay†	4	0 cm - 1978	year core was collected		0.15cm/yr
		23 cm - 1820	large increase in ragweed pollen	agriculture well established in many watersheds	

*See Figure for locations of cores

†Analyses of these cores done under EPA (CBP) Grant Number

SECTION 6

EUTROPHICATION

INTRODUCTION

Chlorophyll degradation products and diatoms were extracted from all of the cores studied to be used as stratigraphic indices of eutrophication and water quality. However, chlorophyll was abandoned because, in many cases, the results appeared anomalous. It would be difficult to use any interpretations of water quality based on chlorophyll distributions in a management program. For example, although the impact of nutrients from sewage effluent is reflected clearly by increases in sedimentary chlorophyll in Back River (Brush and Smith 1974), the influence of sewage input in the Upper Potomac River is not so clearly defined by the stratigraphic chlorophyll profile (Miller and Brush 1979). The latter situation could be due to poor preservation, or it could also result from biological recycling of chlorophyll in the water column by grazers. Dispersion of algal cells away from sources of nutrient also could distort the record preserved in the sediments. In any case, sedimentary chlorophyll was considered unreliable as a consistent indicator of eutrophication due to discrepancies in the data.

Diatoms, on the other hand, are well preserved in estuarine sediments. They are good indicators of water quality and of eutrophication both in biomass and in species composition because many species are sensitive to the chemical, physical and biological properties of the environment (Patrick 1975).

Although diatoms have not been used previously for reconstructing the history of water quality and eutrophication from sediments deposited in the estuaries, they have been used quite successfully for studying the effect of human disturbance on the water quality of lakes (e.g., Stockner and Benson 1967, Bradbury and Waddington 1973, Bradbury 1975 and Brugam 1978).

METHODS

A test of similarity was not performed between diatoms in surface sediment samples and pollen (see Section 5) in order to determine the number of samples necessary for representative spatial data. It was assumed that diatoms are affected by estuarine transport processes in a manner similar to pollen, because as particles they fall within the Stokes law of resistance. Therefore, it is expected that their depositional behavior is similar to that of pollen, in which case only a few samples are necessary to obtain data representative of the spatial distributions.

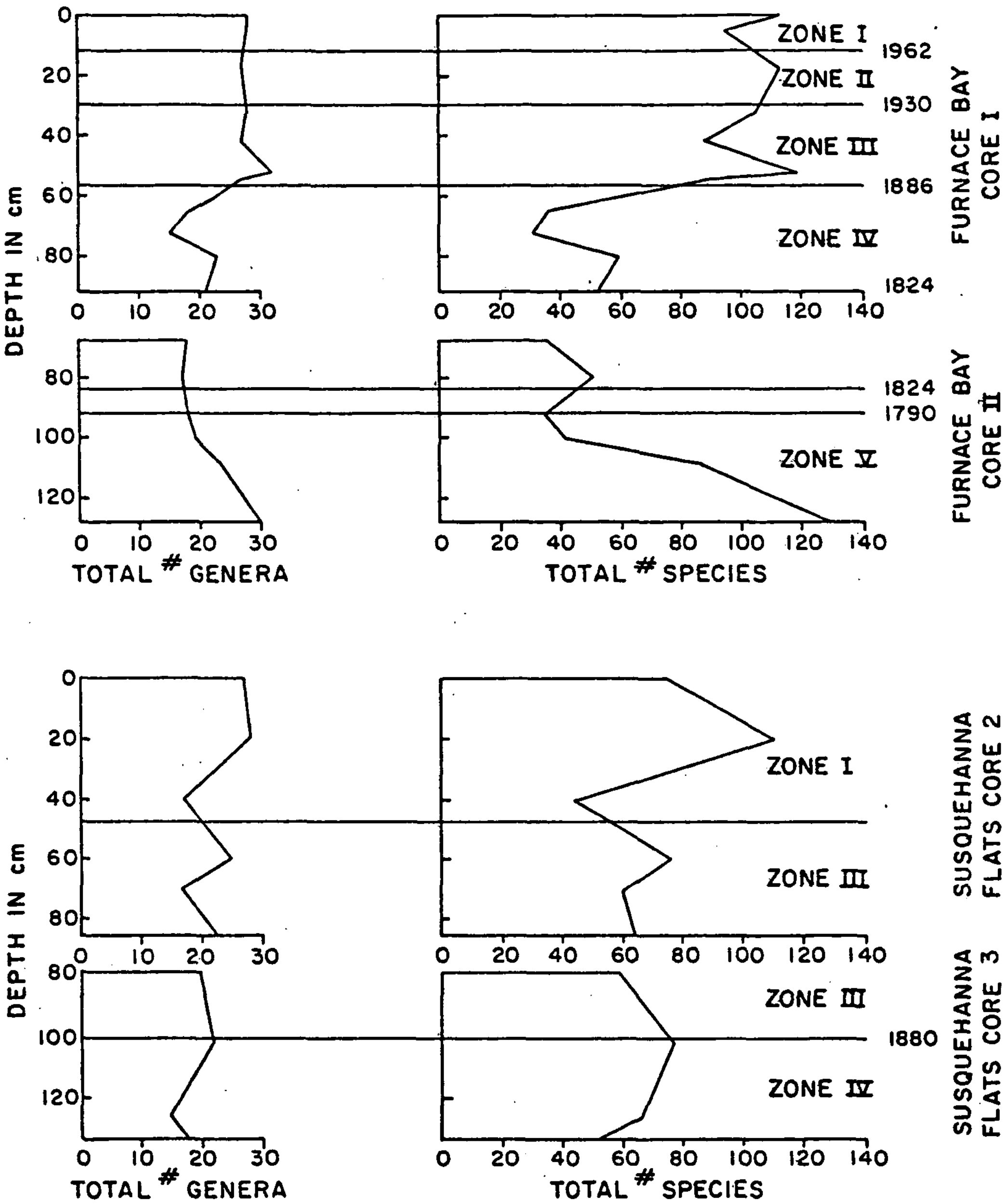


Figure 28. Stratigraphic profile of the total number of genera and species of diatoms in cores from Furnace Bay and Susquehanna Flats.

The procedures for diatom extraction from sediments and slide preparation can be found in Appendix A. Each coverslip was counted in its entirety (approximately 50 transects) to provide estimates of total diatom concentrations at each depth. Normally, each coverslip contained between 50 and 150 diatom frustules. Attempts were made to identify at least 400 frustules at each depth in order to obtain an accurate picture of the total diatom concentration and percentages of genera and species present. For lack of sufficient time, particularly on the longer cores which were sampled more recently, at least 100 but often not more than 200 frustules were identified for some of the depths. In this way, a more complete stratigraphic sequence was achieved.

Core I from Furnace Bay (FB-I) was the most extensively analyzed. Diatoms were identified and enumerated at 10 cm levels with intermediate levels analyzed between levels of major change in order to identify more precisely the horizons where changes occurred. We also studied every 10 cm level from 68 cm to the bottom (130 cm) from the second Furnace Bay core (FB-II).

The amount of sand and other coarse material occurs in greater concentrations in the Susquehanna Flats cores than in those from Furnace Bay, and the concentration of seeds and pollen is much lower. In Core 2 from Susquehanna Flats (SF-2), diatoms were identified and counted at 20 cm intervals and in Core 3 (SF-3) at four levels: 79-81 cm, 102-104 cm, 126-128 cm, and 134-136 cm. This provided sufficient data to identify the major changes in diatom assemblages and compare these changes with those observed in Furnace Bay.

The species identifications were based upon Hustedt (1930), Hohn and Hellerman (1963), and Patrick and Reimer (1966, 1975).

Data were plotted to show total number of genera and species identified at different depths in the four cores (Figure 28). Additional data were plotted to show absolute and relative abundances of the major genera identified (Figures 29 to 32). Graphs were drawn for only those genera comprising at least 10 percent of the total diatoms at one level in one core. The absolute abundance of the diatoms was plotted as diatoms per gram saved sediment weight. The saved sediment is the material left over after the extraction process and is similar in grain size to the diatoms. The saved sediment weight eliminates coal, sand, and other coarse material as well as any organics that were deposited with the diatoms, thus removing from the vertical profiles of the diatoms some of the variations resulting from different sedimentation rates.

RESULTS

Five zones have been identified in Furnace Bay and three zones in Susquehanna Flats (corresponding to three of the same zones in Furnace Bay). These zones are distinguished by differences in numbers of genera and species, absolute abundance of diatoms, dominant genera, and ecological preferences of species (Table 15). Ecological preferences for the diatoms were obtained from EPA report for NERC (Lowe 1974) and Patrick and Reimer (1966, 1975).

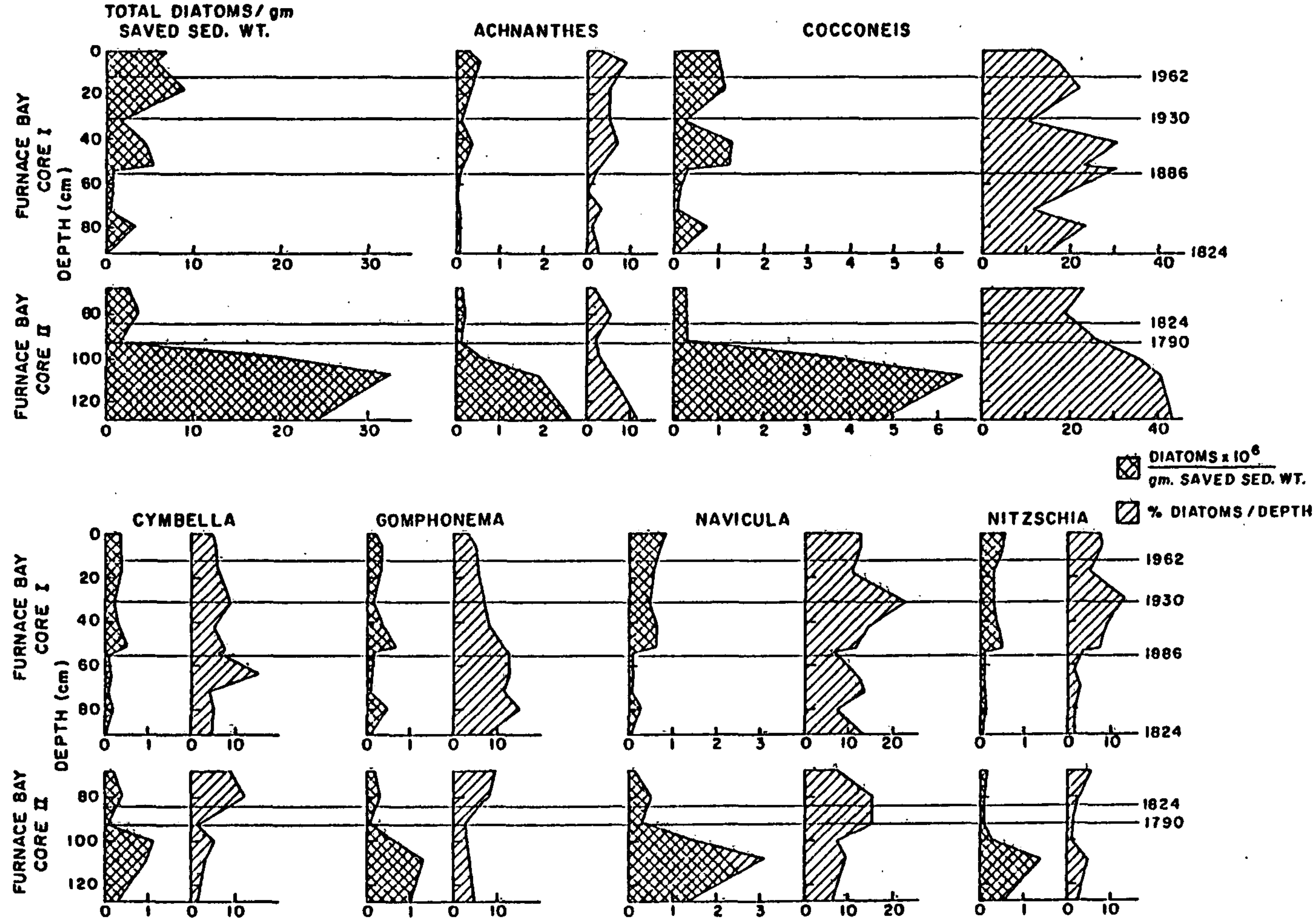


Figure 29. Stratigraphic profiles of total diatoms and total numbers and percent of total diatoms of *Achnanthes, Cocconeis, Cymbella, Gomphonema, Navicula* and *Nitzschia* in cores from Furnace Bay.

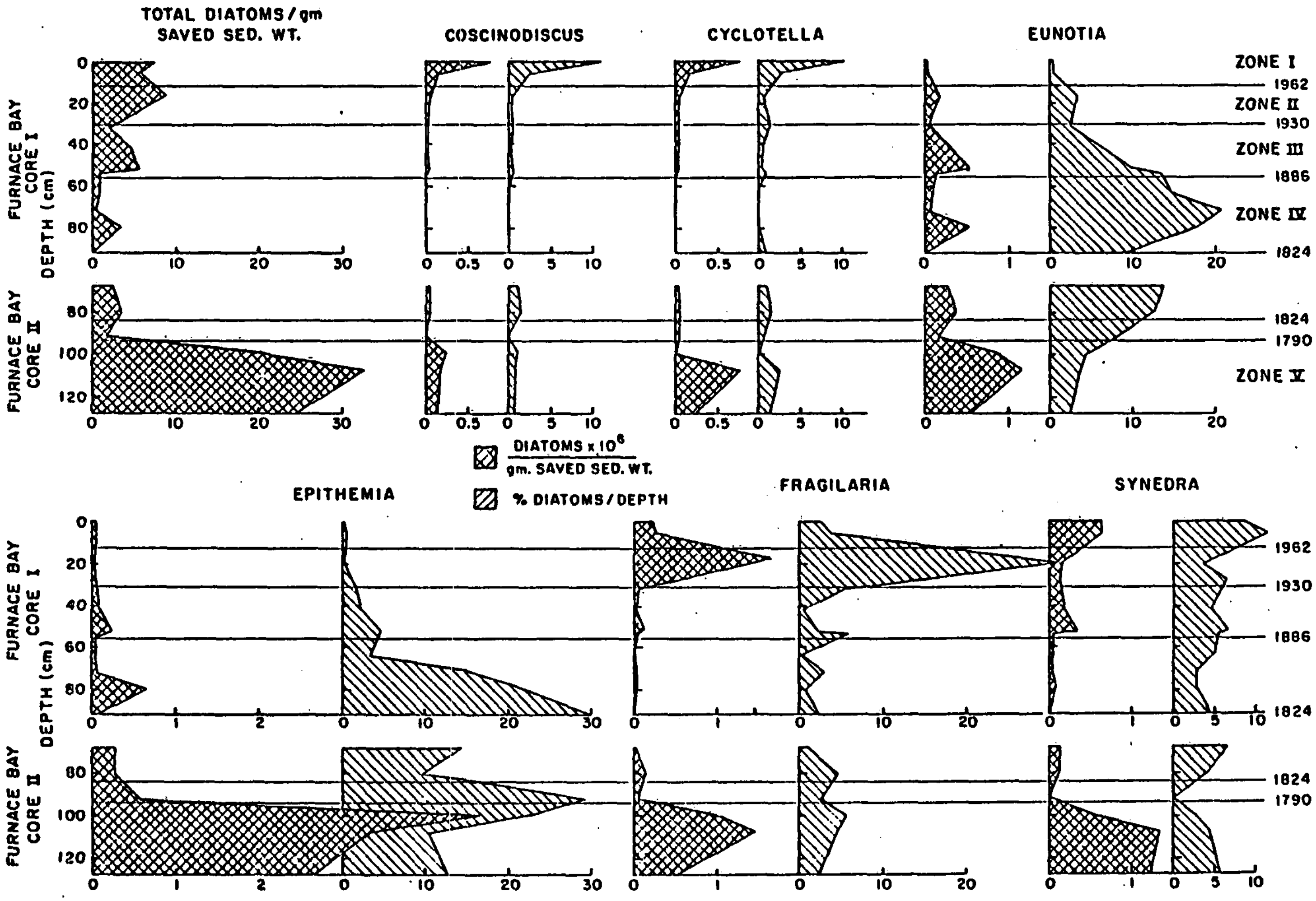


Figure 30. Stratigraphic profile of total diatoms and total numbers and percent of total diatoms of *Coscinodiscus*, *Cyclotella*, *Eunotia*, *Epithemia*, *Fragilaria* and *Synedra* in cores from Furnace Bay.

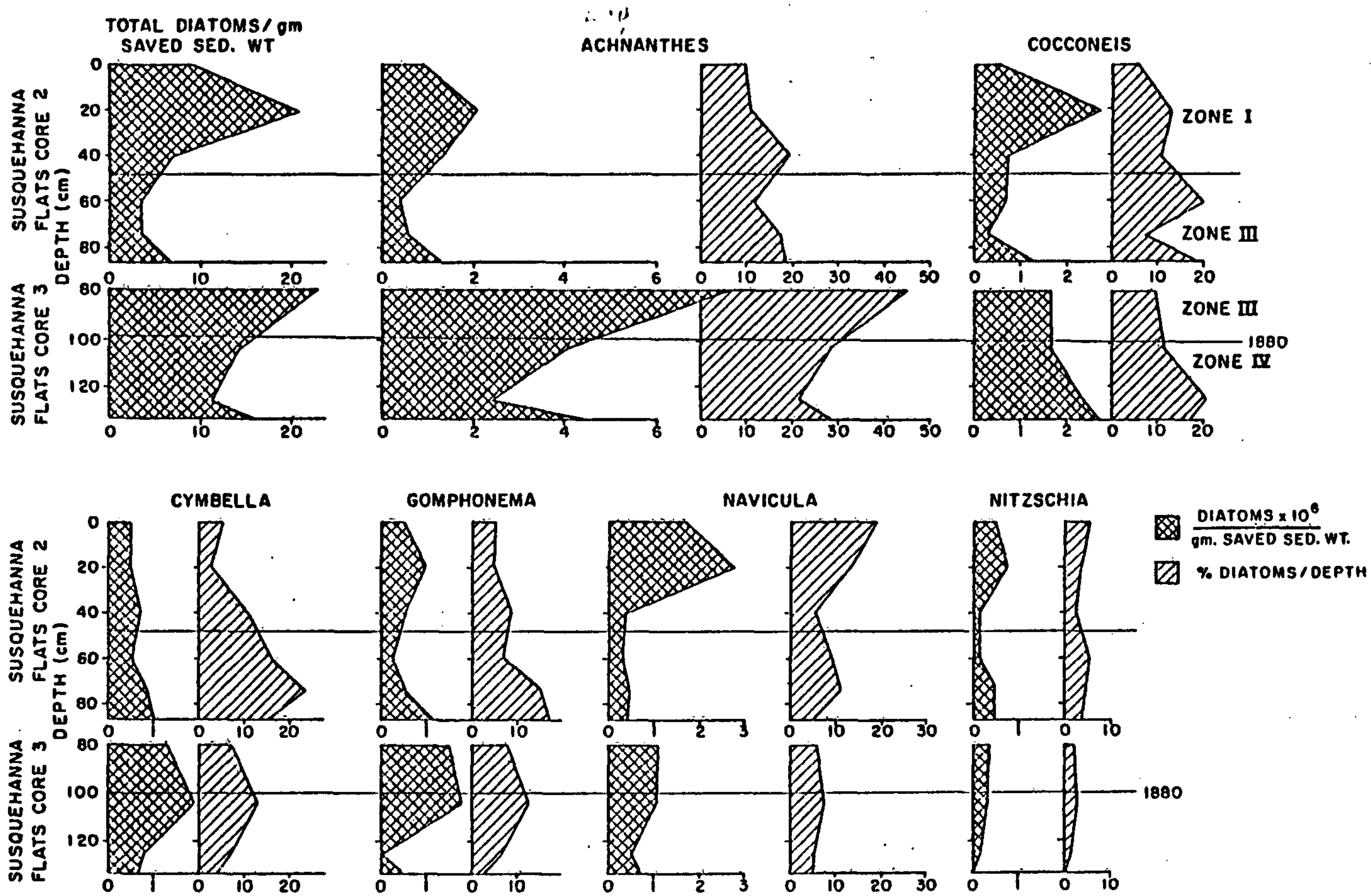


Figure 31. Stratigraphic profiles of total diatoms and total numbers and percent of total diatoms of *Achnanthes*, *Cocconeis*, *Cymbella*, *Gomphonema*, *Navicula* and *Nitzschia* in cores from Susquehanna Flats.

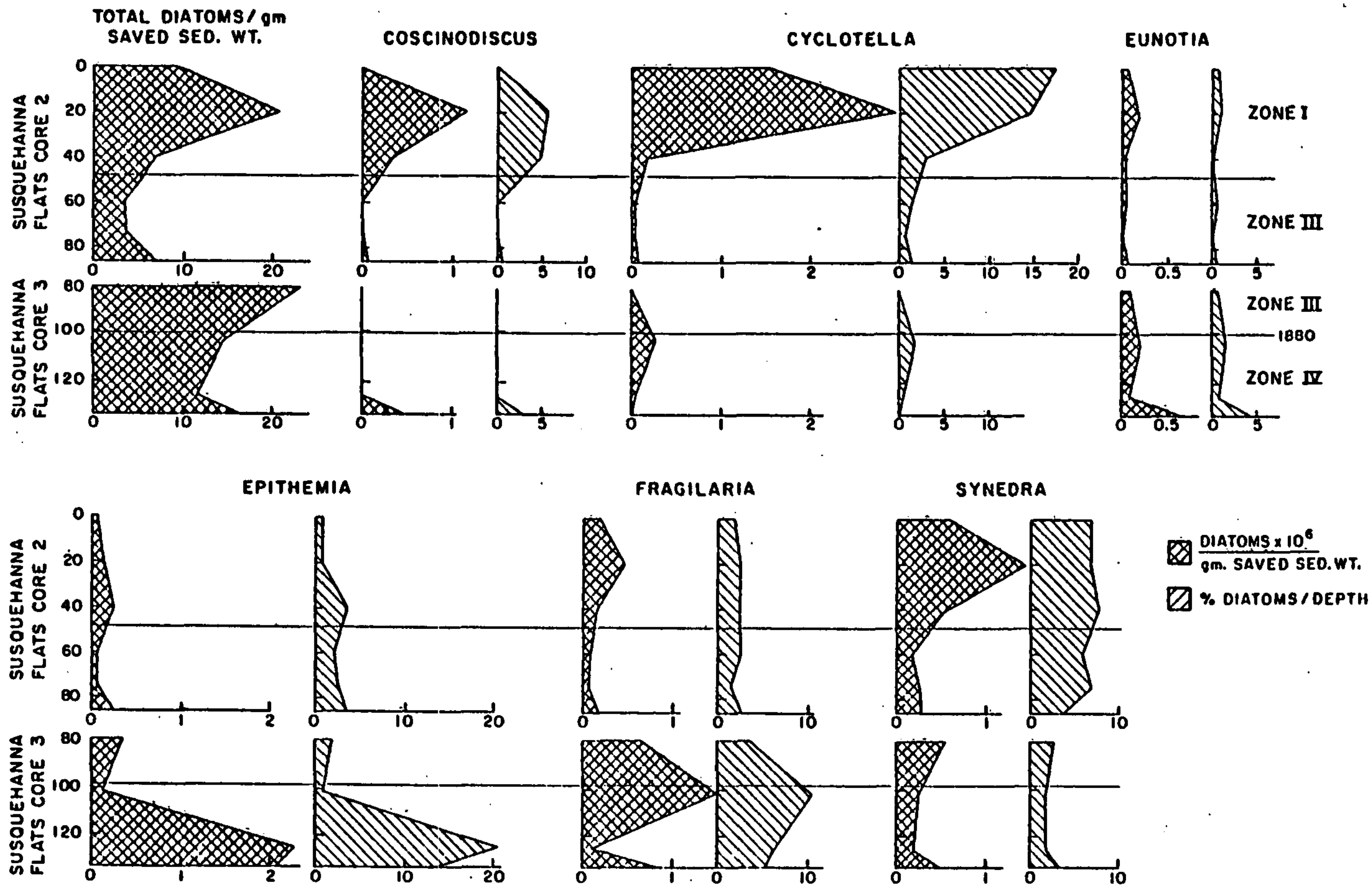


Figure 32, Stratigraphic profiles of total diatoms and total numbers and percent of total diatoms and total numbers and percent of total diatoms of *Coscinodiscus*, *Cyclotella*, *Eunotia*, *Epithemia*, *Fragilaria* and *Synedra* in cores from Susquehanna Flats.

FURNACE BAY I & II

	Average Number of Genera	Average Number of Species	Absolute Abundance No. 1 gm	Dominant Genera	Habitat: plankton #spp	Habitat: periphyte #spp	Habitat: epiphyte #spp	prefer organic environment
ZONE I (1962-1978) FBI 0-12 cm 2 samples	HIGH		MEDIUM	*Cyclotella* *Coscinodiscus* *Synedra* *Navicula*	11	18	2	6
	28	104	6×10^6		High number of planktonic forms; low number of epiphytic forms			MEDIUM-HIGH
ZONE II (1930-1962) FBI 12-30 cm 1 sample	HIGH		MEDIUM	*Fragilaria crotonensis*	3	6	1	4
	27	113	8×10^6		Low number of planktonic forms			MEDIUM
ZONE III (1885-1930) FBI 30-57 cm 4 samples	HIGH		MEDIUM	*Gomphonema* *Nitzschia* *Cymbella* *Eunotia* *Navicula*	3	31	6	7
	28	100	6×10^6		Low number of planktonic forms			HIGH
ZONE IV (1790-1885) FBI 57-93 cm FBII 68-94 cm 7 samples	LOWER		LOW	*Epithemia* *Eunotia* *Cymbella* *Gomphonema*	3	42	20	3
	18	42	1×10^6		High number of epiphytic forms			MEDIUM-LOW
ZONE V (?-1790) FBII 94-128 cm 3 samples pre-agriculture	HIGH		HIGH	*Epithemia* *Achnanthes*	0	17	8	3
	24	86	24×10^6		High number of epiphytic forms			MEDIUM-LOW

Bottom of Core

SUSQUEHANNA FLATS 2 & 3

	Average Number of Genera	Average, Number of Species	Absolute Abundance No. 1 gm	Dominant Genera	Habitat: plankton #spp	Habitat: periphyte #spp	Habitat: epiphyte #spp	prefer organic environment
ZONE I SF2 0-48 cm 3 samples	HIGH		MEDIUM	*Cyclotella* *Coscinodiscus* *Synedra* *Navicula*	14	29	5	7
	24	78	12×10^6		High number of planktonic forms			HIGH
NO CORRESPONDING BLOOM								
ZONE III SF2 & 3 43-98 cm 4 samples	HIGH		MEDIUM	*Gomphonema* *Cymbella* *Achnanthes* *Navicula*	4	28	6	6
	22	65	10×10^6		Lower number of planktonic forms			MEDIUM-HIGH
ZONE IV SF3 98-134 cm 3 samples	LOWER		MEDIUM	*Epithemia* *Cymbella* *Gomphonema*	5	21	8	3
	18	62	14×10^6		Higher number of epiphytic forms			MEDIUM-LOW

Bottom of Core

TABLE 15. SUMMARY OF RATIGRAPHIC DATA ON DIATOM ZOI IN CORES FROM FURNACE BAY AND SUSQUEHANNA FLATS

Date lines on the graphs are based upon sedimentation rates derived from pollen analysis of the cores.

Abundance and Distribution of Fossil Diatom Populations

Core II from Furnace Bay shows a high absolute abundance and a large number of genera and species of diatoms from the bottom of the core up to about 94 cm. Pollen analysis (see Section 5) shows this depth to be near the agricultural horizon; it is dated approximately 1790. Above 94 cm, abundance and number of taxa drops dramatically. This trend continued in both cores from Furnace Bay until approximately 1885 (57 cm depth) (Figures 29 and 30). The reduction in the diatom population at this time can be explained partially by the higher sedimentation and siltation which in all likelihood occurred with the clearing of the land during the 19th century. Patrick (1975) states that homogenization of the habitat by siltation reduces not only substrate diversity but also diversity of light patterns and of current patterns resulting in a decrease in number of species. Other factors may be involved, such as possible blooms of blue-green algae which compete with the diatoms for light and nutrients (Brugam 1978).

In Core FB-I, many new species began invading after 1885 (57 cm depth) and the number of taxa increased to the same numbers of genera and species as before. The absolute abundance never recovered.

A large bloom of *Fragilaria crotonensis* is observed at the 17-19 cm depth in Core FB-I, but overall diversity remains constant.

Two cores (SF-2 and SF-3) from Susquehanna Flats do not appear to predate agriculture. For this reason, they do not show any major decrease in abundance and number of taxa such as the one which characterizes the agricultural horizon in the Furnace Bay cores. The absolute abundance of diatoms in Susquehanna Flats was found to be relatively the same as post-agricultural numbers in Furnace Bay.

The cores from Furnace Bay and Susquehanna Flats also show similar patterns of change in the dominant genera (Figures 29 to 30). This indicates that the regional conditions governing both of these areas are similar. The patterns reflect trends in the ecology of the Upper Chesapeake Bay and not local effects within Furnace Bay or Susquehanna Flats.

Both Furnace Bay and Susquehanna Flats showed a dominance of species of *Epithemia* in the earliest parts of the cores up until about 1880 (57 cm in Core FB-I and 98 cm in Core SF-3). *Epithemia* species showed highest relative abundance in the preagricultural sediment in Core FB-I. After 1880, species of *Epithemia* virtually disappeared from the sediments. The history of the area showed that maximum agricultural clearance, maximum coal mining, and maximum lumbering occurred on a regional basis between 1870 and 1900. Both factors may be related to the subsequent shifts in diatom assemblages found in Furnace Bay and Susquehanna Flats after 1880.

Between 1880 and 1962 (57-12 cm depth in Core FB-I and 98-48 cm depth in Cores SF-2 and SF-3), several genera codominate, including *Gomphonema*, *Cymbella, Nitzschia, Navicula,* and *Eunotia*. Around 1930, a major bloom of *Fragilaria crotonensis* occurred in Furnace Bay.

Since 1962 (0-12 cm depth in Core FB-I and 0-48 cm depth in Core SF-2), there has been a dramatic rise in the number of taxa and absolute abundance of planktonic species in both core areas of which the three genera *Cyclotella, Coscinodiscus,* and *Synedra* became dominant. There was also a noticeable increase in species of *Melosira* and *Stephanodiscus*. The rise in planktonic diatoms and subsequent decline in epiphytes may be correlated with the decline of SAV in recent times (see Section 4).

Cocconeis placentula is a dominant species throughout all four cores at all depths sampled. It has not been included in Table 15 since it does not show much change.

Ecology of Fossil Diatom Populations

Species of diatoms identified from Furnace Bay and Susquehanna Flats have quite similar ecological preferences. Practically without exception, they are known to prefer alkaline water of high mineral content and are insensitive to small amounts of salt. Basically they are indifferent to currents although many prefer some movement of water. Most of the species are found most often in lakes and ponds, with a few representatives from river habitats.

Epiphytic species occurred in greater numbers before 1880, and there have been more planktonic species since 1960. Species of *Epithemia* were dominant before 1880; these species are known to be epiphytic on SAV. Their sudden decrease after 1880 may be correlated with changes in species and number of submerged aquatics or with regional factors which possibly affected both. As mentioned before, their disappearance may be related to the maximum agricultural clearance, mining and lumbering which occurred in this region between 1870 and 1900, and the major floods of 1889 and 1894. Exactly what effects these factors might have on *Epithemia* species is not known.

Since around 1880, species which are known to prefer water high in organic material and which are favored by nutrient enrichment occur in greater abundance, e.g., *Nitzschia fonticola, Nitszchia amphibia, Navicula cryptocephala, Navicula rhyncocephala, Melosira granulata, Cyclotella stelligera, Stephanodiscus dubius, Fragilaria crotonensis,* and *Fragilaria brevistraiata*. This, along with the bloom of *Fragilaria crotonensis* in Furnace Bay, probably is related directly to increased human disturbance of the Upper Chesapeake Bay watershed.

Planktonic species were in greatest abundance from 1960 to the present. Their increase may be a direct response to habitats made available as a result of the recent disappearance of SAV from the Upper Bay. *Cocconeis placentula* is a species found in great abundance at all depths in the cores. *C. placentula* is a eurytopic species capable of growing on many substrates. *C. placentula* and *Synedra rumpens* are the main epiphytes on plants growing today in the Upper Chesapeake Bay.

A major exception to the ecological patterns described above are the species of *Eunotia*, a dominant genus in Furnace Bay from 1830 to 1920 (80-50 cm). Species of *Eunotia* prefer low pH and cannot tolerate any salt. They often are found in nonsubmerged habitats. Extensive acid drainage occurred in the Upper Susquehanna watershed from 1860 to 1920 as a result of mining. A possible explanation for the presence of species of *Eunotia* in Furnace Bay cores is that they flourished in the acid conditions of the upper watershed and were washed into furnace Bay during periods of high flow.

Species of *Achnanthes* occur in much greater abundance and diversity in Susquehanna Flats than in Furnace Bay. The large amounts of sand and coarse material found in Susquehanna Flats may provide a possible explanation for their presence. *Achnanthes* species are extremely small, usually measuring between 3 to 15 microns. They prefer to grow on hard or rocky substrate. The sand and coarse material in Susquehanna Flats (usually measuring about 1 mm in diameter) would provide a suitable substrate for these small diatoms. This substrate is not as available in the siltier deposits of Furnace Bay.

Conclusions

1. Most of the diatom species identified are probably growing and living in the local area. Most of the species show similar ecological preferences (except *Eunotia spp.*) and are normally found in lakes and ponds. Smayda (1971) has shown that settling rates for diatoms range from 1 to 30 m per day. The average depth of the water in Susquehanna Flats and Furnace Bay is 1 to 2 m, so diatoms living in these areas would not have time to move out before settling. Few diatoms would be brought in from other areas, except possibly in times of flooding when resuspension of sediments and faster currents are prevalent.

2. It appears that higher siltation caused by land clearing results in a decrease in numbers of species of diatoms.

3. Cores from Furnace Bay and Susquehanna Flats show a similar diatom stratigraphy despite the fact that sedimentation processes are quite different in the two areas. This indicates that regional conditions govern the ecology of the Upper Chesapeake Bay, and therefore diatom populations are useful for reconstructing the history of water quality for a regional area.

4. The increase in number of species requiring water high in organic material in both areas since the late 19th century suggests that this change is related to increased human disturbance of the Upper Chesapeake Bay watershed including extensive land clearing and increased sewage input.

SECTION 7

REFERENCES

Anderson, R. R. 1972. Submerged Vascular Plants of the Chesapeake Bay and Tributaries. Chesapeake Science 13 (Suppl.):587-589.

Anderson, R. R. et al. In press. Submerged Aquatic Vegetation Distribution --1978. American University, Washington, D. C.

Anderson, T. W. 1974. The Chestnut Pollen Decline as a Time Horizon in Lake Sediments in Eastern North America. Canadian Journal of Earth Sciences 11:678-685.

Bayley, S., V. D. Stotts, P. F. Springer, and J. Steenis. 1978. Changes in Submerged Aquatic Macrophyte Populations at the Head of Chesapeake Bay, 1958-1975. Estuaries 1:73-84.

Bidwell, P. and J. I. Falconer. 1925. History of Agriculture in the Northern United States, 1620-1860. Carnegie Institute. 512 pp.

Bining, A. C. 1938. Pennsylvania Iron Manufacture in the 18th Century. Publications of the Pennsylvania Historical Commission. Vol. IV, Harrisburg, Pennsylvania. 227 pp.

Birks, H. H. 1972. Modern Macrofossil Assemblages in Lake Sediments in Minnesota. In: Quaternary Plant Ecology. John Wiley and Sons, New York. pp. 173-188.

Birks, H. H., M. C. Whiteside, D. M. Stark, and R. C. Bright. 1976. Recent Paleolimnology of Three Lakes in Northwestern Minnesota. Quaternary Research 6:249-272.

Bradbury, J. P. 1975. Diatom Stratigraphy and Human Settlement in Minnesota. The Geological Society of America Special Paper 171. 74 pp.

Bradbury, J. P. and J. C. B. Waddington. 1973. The Impact of European Settlement on Shagawa Lake, Northeastern Minnesota, U. S. A. Quaternary Plant Ecology. 1973:289-307.

Brugam, R. B. 1978. Human Disturbance and the Historical Development of Linsley Pond. Ecology 59:19-36.

Brush, G. S. and L. M. Brush, Jr. 1972. Transport of Pollen in a Sediment-Laden Channel: A Laboratory Study. American Journal of Science 272: 359-381.

Brush, G. S. and J. Smith. 1974. Stratigraphic Evidence of Eutrophication in a Subestuary. Chesapeake Research Consortium Publication 43:135-166.

Brush, G. S., C. Lenk, and J. Smith. In press. The Natural Forests of Maryland: An Explanation of the Vegetation Map of Maryland. Ecological Monographs.

Brush, L. M. Jr. 1965. Sediment Sorting in Alluvial Channels. Society of Economic Paleontologists and Mineralogists Special Publication 12:25-33.

Commonwealth of Pennsylvania. 1915. The Publications of the Pennsylvania Chestnut Tree Blight Commission, 1911-1913. State Printing Office, Harrisburg, Pennsylvania.

County Directors of Maryland. 1956. Cecil County: A Reference Book of History, Business, and General Information. Elkton, Maryland.

Craven, A. O. 1926. Soil Exhaustion as a Factor in the Agricultural History of Virginia and Maryland, 1606-1860. University of Illinois Press, Urbana, Illinois. 189 pp.

Crowder, A. A. and D. G. Cuddy. 1973. Pollen in a Small River Basin: Wilton Creek, Ontario. In: H. J. B. Berks and R. G. West (eds.). Quaternary Plant Ecology, The 14th Symposium of the British Ecological Society. John Wiley and Sons. pp. 61-77.

Davis, M. B. 1973. Pollen Evidence of Changing Land Use Around the Shores of Lake Washington. Northwest Science 47:133-148.

Davis. M. B. and L. B. Brubaker. 1973. Differential Sedimentation of Pollen Grains in Lakes. Limnology and Oceanography 18:635-646.

Davis, M. B., L. B. Brubaker, and J. M. Beiswenger. 1971. Pollen Grains in Lake Sediments: Pollen Percentages in Surface Sediments from Southern Michigan. Quaternary Research 1:450-467.

Davis, M. B. and J. C. Goodlett. 1960. Comparison of the Present Vegetation with Pollen-Spectra in Surface Samples from Brownington Pond, Vermont. Ecology 41:346-357.

Defebaugh, J. E. 1907. History of the Lumber Industry. The American Lumberman, Chicago, Illinois, Vol. 2.

Fenwick, G. H. Unpublished manuscript. Survey of the Submerged Vascular Vegetation of Eastern Bay and Adjacent Tributaries of the Chesapeake Bay, Maryland: June-September, 1976.

Funkhouser, J. W. and W. R. Evitt. 1959. Preparation Techniques for Acid-Insoluble Microfossils. Micropaleontology 5:369-375.

Han, G. 1972. The Delineation of an Exclusion Area Around the Chestertown Outfall on the Chester River and the Back River Sewage Treatment Outfall. Chesapeake Bay Institute Special Report 26.

Hohn, M. H. and J. Hellerman. 1963. Taxonomy and Structure of Diatom Population from Three Eastern North American Rivers Using Three Sampling Methods. Transactions of the American Microscopial Society 82:250-329.

Hollander, M. and D. A. Wolfe. 1973. Non-parametric Statistical Methods. John Wiley and Sons, New York. 115 pp.

Hustedt, F. 1930. Die Susswasser-flora Mitteleuropas. Printed in Germany. 466 pp.

James, H. F. 1928. The Agricultural Industry of Southeastern Pennsylvania: A Study in Economic Geography. Ph. D. Thesis, University of Pennsylvania, Philadelphia, Pennsylvania.

Johnson, G. F. 1929. Agriculture in Pennsylvania: A Study of Trends, County and State, since 1840. Pennsylvania Department of Agriculture General Bulletin, No. 484. Harrisburg, Pennsylvania. 94 pp.

Johnston, G. W. 1881. History of Cecil County, Maryland, and the Early Settlements Around the Head of Chesapeake Bay and on the Delaware River. Reprinted by the Baltimore Regional Publishing Company, Baltimore, Maryland. 548 pp.

Latrobe, B. H. 1817. The Susquehanna River Survey Map. Commissioned by the State of Pennsylvania, Harrisburg, Pennsylvania.

Lemon, J. T. 1972. The Best Poor Man's Country: A Geographical Study of Early Southeastern Pennsylvania. The Johns Hopkins Press, Baltimore, Maryland. 295 pp.

Lintner, S. F. Unpublished manuscript. The Susquehanna River Survey Map.

Livingstone, D. A. 1968. Some Interstadial and Postglacial Pollen Diagrams from Eastern Canada. Ecological Monographs. 38:87-125.

Lowe, R. L. 1974. Environmental Requirements and Pollution Tolerance of Freshwater Diatoms. EPA-670/4-74-005, U. S. Environmental Protection Agency, Washington, D. C. 333 pp.

Martin, A. C. and F. M. Uhler. 1939. Food of Game Ducks in the United States and Canada. U. S. Department of Agriculture Technical Bulletin 634. Washington, D. C. 308 pp.

McNown, J., J. Malaika, and H. R. Pramanik. 1951. Particle Shape and Settling Velocity. International Association of Hydraulic Research, 4th Meeting. 514 pp.

Miller, A. E. 1949. Cecil County, Maryland: A Study in Local History. C and L Print and Specialty Company, Elkton, Maryland. 173 pp.

Miller, A. J. and G. S. Brush. 1979. Rates of Sedimentation and Eutrophication in the Upper Potomac Estuary: A Stratigraphic Study. Final Report. Interstate Commission on the Potomac River Basin, Washington, D. C. 29 pp.

Mueller-Dombois, D. and H. Ellenberg. 1974. Aims and Methods in Vegetation Ecology. John Wiley and Sons. 457 pp.

Orth, R. J. 1976. The Demise and Recovery of Eelgrass, *Zosteria marina*, in the Chesapeake Bay, Virginia. Aquatic Botany 2:141-159.

Patrick, R. 1967. Diatom Communities in Estuaries. Estuaries. Pub. No. 83. American Association for the Advancement of Science, Washington, D. C. pp. 311-315.

Patrick, R. 1975. Stream Communities. Ecology and Evolution of Communities. The Belknap Press of Harvard University Press. pp. 445-459.

Patrick, R. and C. W. Reimer. 1966. The Diatoms of the United States, Vol. 1. Monographs No. 13. Academy of Natural Science of Philadelphia. 688 pp.

Patrick, R. and C. W. Reimer. 1975. The Diatoms of the United States, Vol. II, Part I. Monographs No. 13. Academy of Natural Science of Philadelphia. 213 pp.

Perkins, S. O. and W. H. Moore. 1927. Soil Survey of Cecil County, Maryland. Bureau of Chemistry and Soils, U. S. Department of Agriculture, Washington, D. C. pp. 1-9.

Praeger, R. L. 1913. On the Bouyancy of the Seeds of Some Brittanic Plants. Scientific Proceedings of the Royal Dublin Society. 14:13-62.

Ridley, H. N. 1930. The Dispersal of Plants Throughout the World. Reeve, Ashford, England.

Ronsteel, J. A. and T. C. Bass. 1940. Erosion and Related Land Use Conditions in the Conestoga Area, Pennsylvania. Soil Conservation Service Erosion Survey No. 15, U. S. Department of Agriculture, Washington, D. C. pp. 1-10.

Sculthorpe, C. D. 1967. The Biology of Aquatic Vascular Plants. Edward Arnold Ltd., London. 610 pp.

Smayda, T. J. 1971. Normal and Accelerated Sinking of Phytoplankton in the Sea. Marine Geology. 11:105-122.

Snedecor, G. W. and W. G. Cochran. 1976. Statistical Methods. The Iowa State University Press, Ames, Iowa. 593 pp.

Southwick, C. H. and F. W. Pine. 1975. Abundance of Submerged Vascular Vegetation in the Rhode River from 1966 to 1973. Chesapeake Science 16(1):147-151.

Stark, D. M. 1971. A Paleolimnological Study of Elk Lake in Itasca State Park, Clearwater County, Minnesota. Ph. D. Thesis, University of Minnesota. 178 pp.

Steenis, J. H. et al. 1962. Observations on Distribution and Control of Eurasian Milfoil in Chesapeake Bay, 1961. Proceedings of the Northeastern Weed Control Conference 16:442-448.

Steenis, J. H. 1970. Status of Eurasian Water Milfoil and Associated Submerged Species in the Chesapeake Bay Area--1969. Administrative Report to R. Andrews, U. S. Fish and Wildlife Service, Patuxent Wildlife Research Station. 27 pp.

Steer, H. B. 1948. Lumber Production in the United States, 1799-1946. Miscellaneous Publication No. 669, U. S. Department of Agriculture, Washington, D. C. 233 pp.

Stevenson, J. C. and N. M. Confer. 1978. Summary of Available Information on Chesapeake Bay Submerged Vegetation. U. S. Department of the Interior, Fish and Wildlife Service Biological Services Program, Washington, D. C. 335 pp.

Stockner, J. G. and W. W. Benson. 1967. The Succession of Diatom Assemblages in the Recent Sediments of Lake Washington. Limnology and Oceanography 12:513-532.

Susquehanna River Basin Commission. 1973. Comprehensive Plan for Management and Development of the Water Resources of the Susquehanna River Basin. Mechanicsburg, Pennsylvania. 127 pp.

Susquehanna River Basin Study Coordinating Committee. 1970. Susquehanna River Basin Study: Appendix C--Economics and Geography. Susquehanna River Basin Commission, Mechanicsburg, Pennsylvania. pp. C-I-1--C-X-5.

Tauber, H. 1965. Differential Pollen Dispersion and the Interpretation of Pollen Diagrams. Geological Survey Denmark II Series No. 89:1-69.

Trimble, S. W. 1974. Man-Induced Soil Erosion on the Southern Piedmont: 1700-1970. University of Wisconsin, Milwaukee. 180 pp.

Tonkin, J. D. 1940. The Last Raft. Harrisburg, Pennsylvania, The Author, 145 pp.

Upper Chesapeake Watershed Association, Inc. 1972. Literature Search on the Upper Chesapeake Watershed, Elkton, Maryland. 81 pp.

U. S. Army Corps of Engineers, Baltimore District. 1975. Impact of Tropical Storm Agnes on Chesapeake Bay. Baltimore, Maryland. 45 pp.

U. S. Bureau of the Census, Department of Commerce. Census Data for years 1844, 1860, 1870, 1880, 1890, 1920, 1924, 1949, 1964, 1977. Washington, D. C.

Watts, W. A. 1967. Late-glacial Macrofossils from Minnesota. In: Quaternary Paleoecology (Cushing, E. J. and Wright, H. E., eds.). Yale University Press, New Haven, Connecticut. pp. 89-99.

APPENDIX

MODIFICATION OF METHODS IN QUALITY ASSURANCE REPORT

Diatom Extraction Procedure

Materials: 50 mℓ beakers
80-95% H_2O_2 (hydrogen peroxide)
25% HCℓ
HNO_3 (concentrated)
$K_2Cr_2O_7$
95% EtOH
600 mℓ beakers

Method:

1. Weigh beakers (50 mℓ beakers).

2. Place one (1) mℓ sediment sample in beaker and reweigh.

3. Place in drying oven overnight and reweigh.

4. Add 25 mℓ H_2O_2 and place watch glass over beaker.

   a. Let stand for one hour to overnight; swirling occasionally to reduce foam.

   b. Warm over low heat (@80 C); be careful not to let it foam over; continue heating until the reaction begins to boil exothermically and produce "white smoke."

   c. Remove from heat. When reaction is complete, add distilled H_2O and let stand overnight.

(This step disperses the sample and oxidizes some organics.)

5. Carefully decant.

6. Add 25 mℓ 25% HCℓ, and heat for 30 minutes. Remove from heat and add distilled water. Let stand for 24 hours.

(This step removes carbonates and small fragments.)

7. Carefully decant.

8. Add 25 mℓ concentrated HNO_3 and a pinch of $K_2Cr_2O_7$. Boil for two hours. Remove from heat, add H_2O and let stand for 24 hours.

(This step oxidizes organics.)

9. Carefully decant.

10. Add distilled H_2O and let stand for 24 hours (Wash #1).

11. Carefully decant.

12. Wash #2.

13. Carefully decant.

14. Wash #3.

15. Carefully decant.

16. SQUIRT in distilled H_2O to the 40 mℓ mark and wait 30 seconds. Pour supernatant into 600 mℓ beaker. Repeat this 9 more times. (This step is used to remove the coarse fraction of the sample.)

    a. After the 10th decantation, place the beaker and residue in the drying oven. After 24 hours weigh beaker and residue. Clean the beaker and reweigh.

    b. Let the beaker with supernatant stand for 24 hours.

17. Pour off supernatant carefully.

18. Transfer residue to clean 50 mℓ beaker (pre-weighed). Use 95% EtOH. Put in drying oven.

19. Allow to sit at room temperature and then weigh.

20. Add 10 mℓ distilled water and stir with soft tip to disperse.

21. Transfer sample to storage bottle (premarked at 50 mℓ volume). (Use distilled H_2O to store diatoms.)

Methods described above are a modification by James Stasz of Funkhouser, John W. and William R. Evitt (1959). Preparation Techniques for Acid-Insoluble Microfossils, Micropaleontology, Vol. 5, No. 3, pp. 369-375.

Diatom Slide Preparation

Materials: Corning plain micro slides 3 x 1"
Corning cover glass No. 1 22 mm^2
1 mℓ tuberculin syringes
1 mℓ graduated glass pipets
Warming plate and hot plate
Hyrax mounting medium

Method:

The diatoms are diluted in distilled water to desired concentration (different for every sample), and then 0.06 mℓ of this solution are measured onto a cover slip using a graduated glass pipet attached to a tuberculin syringe. The cover slips are heated over a warming plate until the water drop dries (about 15 minutes). One drop of Hyrax is added to each cover slip and two coverslips are permanently mounted to one slide.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA 600/8-80-040	2. SAV 3	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE BIOSTRATIGRAPHY OF CHESAPEAKE BAY AND ITS TRIBUTARIES - A Feasibility Study		5. REPORT DATE Date of Approval April, 1980
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Grace S. Brush, Frank W. Davis, Sherri Rumer		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Geography and Environmental Engineering, The Johns Hopkins University, Baltimore, Maryland 21218		10. PROGRAM ELEMENT NO. 2BA711
		11. CONTRACT/GRANT NO. Grant #R805962
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency, Chesapeake Bay Program, 2083 West Street, Suite 5-G, Annapolis, Maryland 21401		13. TYPE OF REPORT AND PERIOD COVERED Final 7-1-78 to 10-31-79
		14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

Seeds of submerged aquatic vegetation (SAV), diatoms and pollen of terrestrial plants extracted from sedimentary cores 1 to 1.5 m long, in estuarine tributaries, yield information regarding changes in SAV populations, eutrophication and sedimentation rates since European settlement. Cores taken from undisturbed depositional areas represent regional conditions with respect to eutrophication and sedimentation, because diatoms and pollen are affected by estuarine transport processes in such a manner that local patchiness is erased but regional differences are not obliterated. Vertical (historical) changes in diatom and pollen distributions therefore can be described for a whole region with only a few cores because the data from 1 sample at the locale is representative of the whole locale.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
	Agriculture, Biostratigraphy, Chesapeake Bay, core, diatom, estuary, eutrophication, pollen, sedimentation, seed, settlement, SAV, tributary	

18. DISTRIBUTION STATEMENT Release unlimited	19. SECURITY CLASS (This Report) unclassified	21. NO. OF PAGES 98
	20. SECURITY CLASS (This page) unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

INSTRUCTIONS

1. **REPORT NUMBER**
Insert the EPA report number as it appears on the cover of the publication.

2. **LEAVE BLANK**

3. **RECIPIENTS ACCESSION NUMBER**
Reserved for use by each report recipient.

TITLE AND SUBTITLE
Title should indicate clearly and briefly the subject coverage of the report, and be displayed prominently. Set subtitle, if used, in smaller type or otherwise subordinate it to main title. When a report is prepared in more than one volume, repeat the primary title, add volume number and include subtitle for the specific title.

5. **REPORT DATE**
Each report shall carry a date indicating at least month and year. Indicate the basis on which it was selected *(e.g., date of issue, date of approval, date of preparation, etc.).*

6. **PERFORMING ORGANIZATION CODE**
Leave blank.

7. **AUTHOR(S)**
Give name(s) in conventional order *(John R. Doe, J. Robert Doe, etc.)*. List author's affiliation if it differs from the performing organization.

8. **PERFORMING ORGANIZATION REPORT NUMBER**
Insert if performing organization wishes to assign this number.

9. **PERFORMING ORGANIZATION NAME AND ADDRESS**
Give name, street, city, state, and ZIP code. List no more than two levels of an organizational hirearchy.

10. **PROGRAM ELEMENT NUMBER**
Use the program element number under which the report was prepared. Subordinate numbers may be included in parentheses.

11. **CONTRACT/GRANT NUMBER**
Insert contract or grant number under which report was prepared.

12. **SPONSORING AGENCY NAME AND ADDRESS**
Include ZIP code.

13. **TYPE OF REPORT AND PERIOD COVERED**
Indicate interim final, etc., and if applicable, dates covered.

14. **SPONSORING AGENCY CODE**
Insert appropriate code.

15. **SUPPLEMENTARY NOTES**
Enter information not included elsewhere but useful, such as: Prepared in cooperation with, Translation of, Presented at conference of, To be published in, Supersedes, Supplements, etc.

16. **ABSTRACT**
Include a brief *(200 words or less)* factual summary of the most significant information contained in the report. If the report contains a significant bibliography or literature survey, mention it here.

17. **KEY WORDS AND DOCUMENT ANALYSIS**
(a) DESCRIPTORS - Select from the Thesaurus of Engineering and Scientific Terms the proper authorized terms that identify the major concept of the research and are sufficiently specific and precise to be used as index entries for cataloging.

(b) IDENTIFIERS AND OPEN-ENDED TERMS - Use identifiers for project names, code names, equipment designators, etc. Use open-ended terms written in descriptor form for those subjects for which no descriptor exists.

(c) COSATI FIELD GROUP - Field and group assignments are to be taken from the 1965 COSATI Subject Category List. Since the majority of documents are multidisciplinary in nature, the Primary Field/Group assignment(s) will be specific discipline, area of human endeavor, or type of physical object. The application(s) will be cross-referenced with secondary Field/Group assignments that will follow the primary posting(s).

18. **DISTRIBUTION STATEMENT**
Denote releasability to the public or limitation for reasons other than security for example "Release Unlimited." Cite any availability to the public, with address and price.

19. & 20. **SECURITY CLASSIFICATION**
DO NOT submit classified reports to the National Technical Information service.

21. **NUMBER OF PAGES**
Insert the total number of pages, including this one and unnumbered pages, but exclude distribution list, if any.

22. **PRICE**
Insert the price set by the National Technical Information Service or the Government Printing Office, if known.