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Response of a Salt Marsh to Oil Spill and Cleanup: Biotic and Erosional Effects in the Hackensack Meadowlands, New Jersey

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June 1978

RESPONSE OF A SALT MARSH TO OIL SPILL AND CLEANUP

Biotic and Erosional Effects in the Hackensack Meadowlands, New Jersey

by

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL - Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This study consists of an assessment of the biological and erosional effects of a crude oil spill in the Hackensack River, New Jersey, and subsequent cleanup operations. The information gained as a result of this experience will be valuable to oil spill onscene coordinators when planning and responding to future spills under similar environmental conditions. Personnel responsible for future damage assessment surveys should also find the report useful. For further information, please contact the Oil and Hazardous Spills Branch of the Resource Extraction and Handling Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

This study addresses the biological and erosional response of portions of the Hackensack Meadowlands estuarine marsh to the Wellen Oil Company number 6 crude oil spill of late May 1976, and the subsequent cleanup operations. Cleanup included cutting and removal of oiled grasses of the species *Spartina alterniflora* from the bank of the Hackensack River. Data were gathered from several locations along the riverbank and in the inner marsh during four sampling sessions, at approximately 4-month intervals, throughout the year following the spill. The productivity of the marsh plants, the composition of marsh soil invertebrate communities, the presence of oil in the substrate, and erosional trends were monitored. Results suggest that cutting heavily oiled *Spartina* soon after contamination saved the plants from dying by root suffocation. However, the foot traffic associated with cutting is implicated as having made the river bank susceptible to severe erosion by boat wakes and other sources of erosive energy. It is concluded that cutting is only desirable in a limited range of circumstances, determined by the characteristics of the contaminating oil, the biology of affected plants, and the time of year.

CONTENTS

CONTENTS (cont.)

FIGURES

TABLES

ACKNOWLEDGMENTS

Sincere thanks are extended to Chester Mattson, Donald Smith, Nicholas Vallario and other members of the Hackensack Meadowlands Development Commission who permitted this research to be performed in their jurisdictional area. Mr. Smith was particularly helpful in providing information about the spill and helping the research team become familiar with the area.

Robert Castle was responsible in large part for the sampling design. He also provided information and prepared much of the text on erosional processes. Leon Crain performed the onsite observations of the oil spill cleanup operations and contributed most of the text that describes them.

Michael Slack and Diane Renshaw edited the manuscript and provided many helpful suggestions. Susan Samse prepared the graphics, Diane Renshaw provided the botanical line drawings, and Margaret Chatham and Donna Murzi typed and produced the final report. The study was conducted under the Oil and Hazardous Materials Program of URS Company; Bill Van Horn, program manager.

Special thanks are due to Leo McCarthy and Stephen Dorrler of the Environmental Protection Agency, without whose support this work would not have been possible.

SECTION 1

INTRODUCTION

This study addresses the response of salt marsh communities in the Hackensack Meadowlands, New Jersey (Figure 1), to an oil spill that occurred in late May 1976. A primary objective of the study was to develop recommendations for minimizing the adverse biological and erosional impacts of cleanup operations in future spills.

DESCRIPTION OF THE STUDY AREA

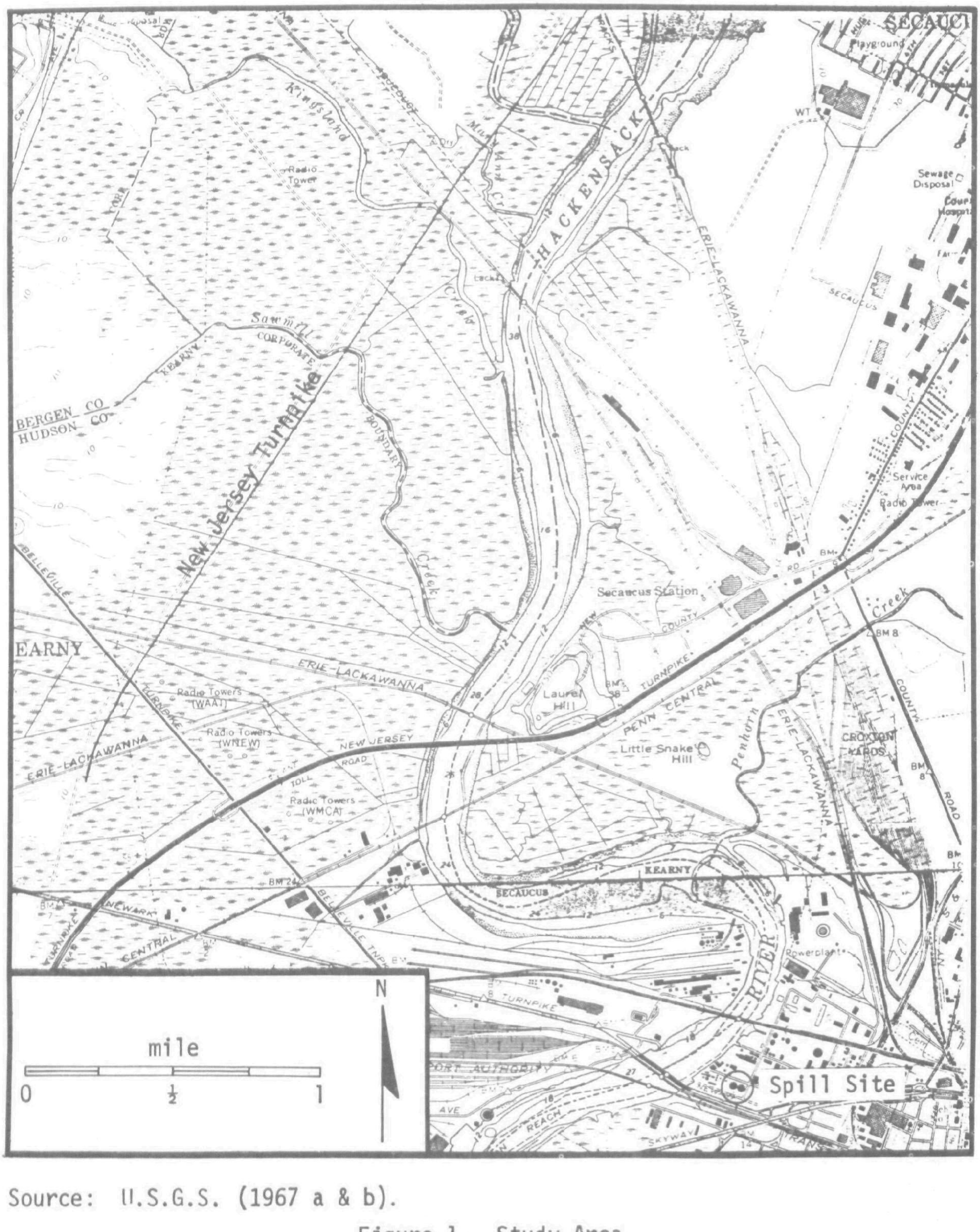
The Hackensack Meadowlands comprise a great complex of estuarine marshes in northern New Jersey, across the Hudson River from New York City. Although most of the surrounding region has been built on to provide industrial and residential facilities, approximately 6,300 acres of water and marshland remain essentially undeveloped (Mattson and Vallario, 1976). The distinguishing characteristics of this undeveloped region are described below.

The Hackensack River flows through the marshes, carrying nutrient-rich sediments from inland. As the river slows on its approach to the sea, it deposits a portion of these sediments. Some of these, as well as materials contained in industrial and sanitary effluents from the towns and cities nearby, become incorporated into the marsh soil and feed the plants growing there.

Organic materials in the sediment, along with the remains of dying plants, are decomposed by bacteria. The decomposition process requires more oxygen than is available in the benthic environment. The marsh soil becomes anaerobic, and the dead stems of marsh grasses only partially decay. The partly decomposed plant material accumulates after each growing season and adds to the peat substrate.

The Atlantic Ocean also exerts a considerable influence on the marsh ecosystem. Tidal waters move upriver twice daily. They run over the soil and flush away wastes. The mixture of sea and river water produces a brackish-water environment that eliminates competition from salt-intolerant species, and allows the salt-adapted marsh grasses to thrive.

The naturally dominant plants of saline marshes in this portion of the United States belong to the genus *Spartina*. One species, *Spartina patens*, grows in the higher portions of marsh and is of no concern in this study. However, the salt marsh cord grass, *Spartina alterniflora*, is of primary importance in the Hackensack Meadowlands and was therefore the object of considerable observation during this investigation. This species is depicted in Figure 2. *Spartina* inhabits the frequently inundated zones adjacent to



Source: U.S.G.S. (1967 a & b).

Figure 1. Study Area

Figure 2. Spartina alterniflora

creeks and channels in the marsh.* It has colonized much of the broad expanse of mudflats in the inner or back marsh of the Hackensack Meadowlands, away from the main river channel. In the downriver portions of the Meadowlands, Spartina alterniflora populates the banks of the Hackensack River.

Although the leafy tissues and aerial stems of the Spartina plant die back each year, the underground stems, or rhizomes, and roots are perennial structures. These organs, which are essential to the plant's vegetative survival, require oxygen to survive, but cannot obtain it from the oxygen-poor soils in which the plant commonly grows. They obtain necessary oxygen and release carbon dioxide waste through a system of open spaces and hollow, air-filled tubes that open to the atmosphere through pores in the leaves, called stomata. Specially adapted guard cells close when the leaves are inundated, to prevent the air spaces from filling with water (Teal and Teal, 1969).

Spartina is a salt-tolerant plant. It actually grows quite vigorously in freshwater environments, but is infrequently observed there because it cannot compete successfully with species that are specifically adapted for living in freshwater marshes (Teal and Teal, 1969).

One such freshwater plant is Phragmites communis, a common reed that grows in a wide range of habitats. Phragmites, shown in Figure 3, is another dominant plant of the Hackensack Meadowlands, and the only species besides Spartina alterniflora that received intensive study in the present investigation. Phragmites can tolerate dry ground. It grows on the higher banks and remains of old dikes. It also is the dominant species in much of the marshland in the northern portion of the study area.

Just as Spartina grows well in freshwater, so can Phragmites tolerate a certain amount of salt. Its presence in the upper limits of salt marshes is fairly common, but it does not grow well when the salt concentration (chloride) in the soil water exceeds about 1.2 percent (Haslam, 1972). Phragmites also seems to be similar to Spartina in the way its roots obtain oxygen. They contain some air-filled tissue and do not seem to be starved for oxygen when the plant bases are inundated (Buttery et al., 1965).

Interested readers are referred to a biological inventory of the marshes and waterways in the Meadowlands compiled by the Hackensack Meadowlands Development Commission (1975), for more detailed information on the study area.

OIL SPILL CLEANUP HISTORY

Spill Incident

On the night of May 25-26, 1976, at the site of the Wellen Oil Company storage facility in Jersey City, New Jersey, an oil tank ruptured. The

*The term Spartina alone will refer from here on to the species Spartina alterniflora, unless specific reference is made to the genus at large or to some other species.

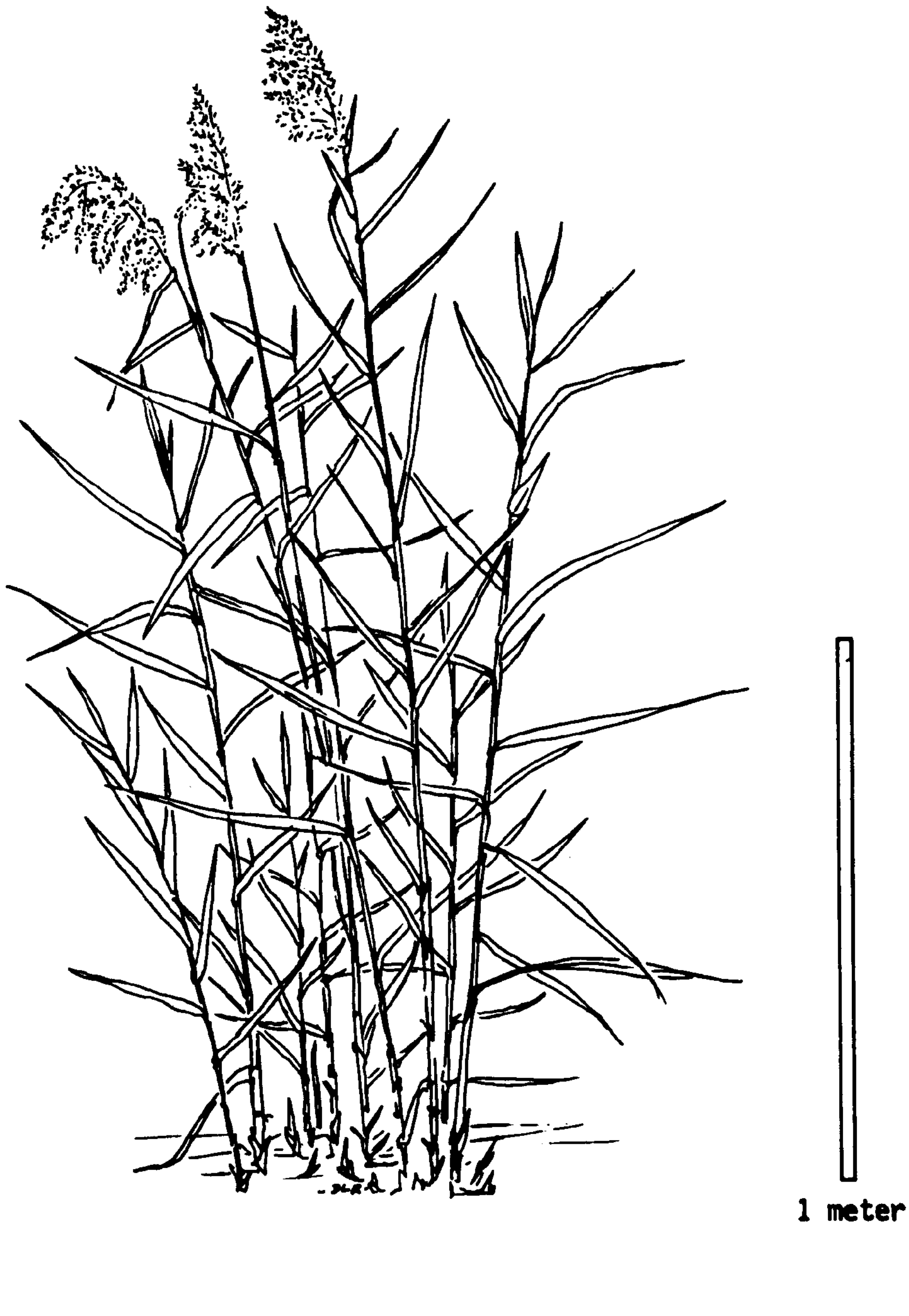


Figure 3. Phragmites communis

containment berm surrounding the tank failed, resulting in the release of approximately 2 million gallons of No. 6 crude oil into the Hackensack River. The flood tide carried the oil approximately 3.7 kilometers upriver into the vicinity of the Kingsland Creek-Sawmill Creek area of the Hackensack Meadowlands. A strong east wind directed the bulk of the oil to the west bank of the river. Currents of more than 2 meters per second (4 knots) in conjunction with the wind threatened to carry the oil up several small channels into the interior of the marsh. Booms, placed across the entrances to the most important channels, failed against the strong currents. As a result, most of the back marsh and mudflat areas were exposed to the spilled oil. The most severely affected regions are shown on the map in Figure 4. The viscous oil adhered to most plants and vegetational debris within the tidal range. Much of the contaminated vegetation in the marsh interior, however, was situated in the path of tidal currents, which washed some of the oil from the plants. The pattern of soil contamination was less apparent. In some locations, it seemed that only the less water-saturated sediment permitted adhesion; elsewhere, all the substrate was contaminated. The large mudflat area in the vicinity of Sawmill Creek was exposed to a great quantity of oil. The oil did not strongly adhere to the substrate and was ultimately removed by tidal flushing.

Marsh Cutting Operations

After most of the mobile oil on the Hackensack River was contained or removed by cleanup contractors, local, governmental, and private experts decided that cutting was a viable method of removing the vegetation that had been contaminated and which continued to release oil to the waters. On June 13, 1977, 17 days after the spill, the cutting operation was started by Disch Construction Company. The operation took place on the western bank of the Hackensack River from the New Jersey Turnpike Bridge to approximately 0.5 kilometers north of Kingsland Creek, a total distance of 2.4 kilometers. The cut area, shown in Figure 5, included the most heavily contaminated vegetation. A horizontal path of marsh plants, approximately 3 meters wide, was cut and removed from the site. The marsh plants were cut 5 to 15 centimeters from the soil surface. Cutting was terminated on June 30.

The cutting operation was carried out only during daylight hours. Marsh cutting could only take place during the lower tidal cycle because at other times the Hackensack River bank was underwater, making cutting difficult and dangerous. As a result, crews worked 8 to 10 hours each day.

One crew was employed in the cutting operation. This seven-man crew consisted of one foreman, one cutter, and five plant debris handlers. The work crew were provided with one 16-foot motorboat, 2 flat-bottomed boats, 2 scythes, and 7 pitchforks and clamforks. This crew cut and removed plant debris at an average rate of 140 linear meters of river bank shoreline per day.

The cutter used an aluminum handled brush scythe with a 46-centimeter blade. After 10 to 15 minutes of cutting, the scythe blade became dull and

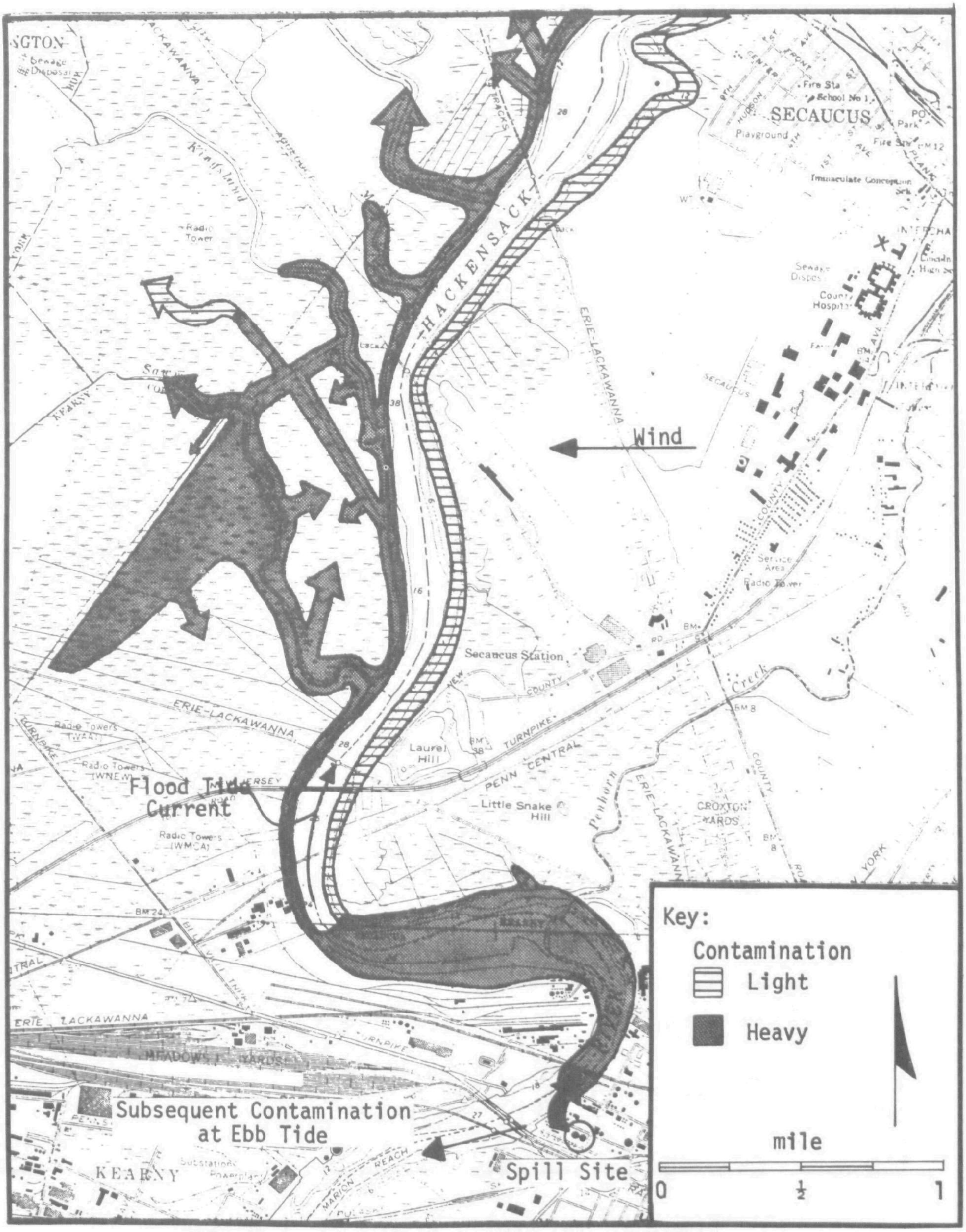


Figure 4. Contaminated Regions in the Hackensack Meadowlands

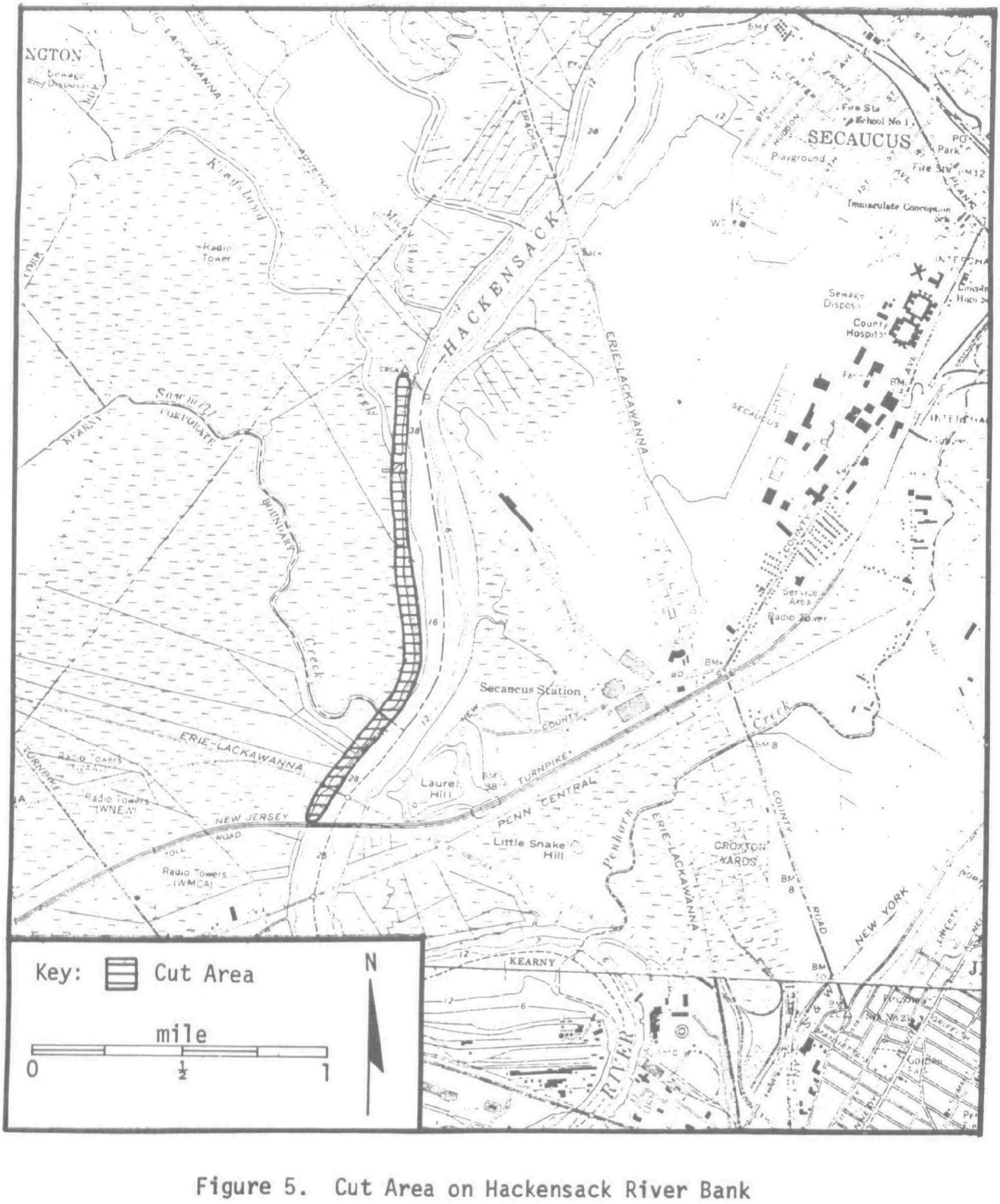


Figure 5. Cut Area on Hackensack River Bank

required sharpening by file. One cutter was able to keep ahead of the 5 people raking and loading the plants into the flat-bottomed boats.

Three people were employed in raking the cut vegetation into small stacks on the river bank. About 6 to 10 of these stacks would accumulate on the shoreline prior to removal. Since protective ground cover beneath the stacked plants was not employed, oil was able to drain from the stacks onto the soil. On occasion stacks were left overnight, allowing oil to leach from these stacks and be washed away at high tide. Protective booms, which might have contained the oil, were not used.

Two people using pitchforks transferred the plant material from the stacks to the two flat-bottomed boats. The flat-bottomed boats were used as barges to transport the cut plants to an interim storage area beneath the New Jersey Turnpike Bridge. At the storage area, neither protective ground cover on the shoreline and embankment nor protective booming of the shoreline were observed. Some of the debris was left at this site until November. The plants were subsequently removed to a landfill site that had been approved by the State of New Jersey.

SECTION 2

CONCLUSIONS

The following conclusions are suggested by the observational and supporting quantitative data gathered during this study:

1. Damage to *Spartina alterniflora* plants caused by the Wellen oil spill resulted primarily from the physical, not the chemical (toxic) properties of the oil. Oil coated the plants, prevented gaseous exchange with the atmosphere, and ultimately caused the plants' roots and rhizomes to suffocate.

2. Mortality was highest in heavily oiled *Spartina alterniflora* plants that were neither washed clean by tides nor cut.

3. Other oiled plants, which were less heavily oiled or naturally flushed clean, may have sustained some damage, as evidenced by decreased productivity. However, this result may be an artifact of the sampling procedure and the distribution of the plants.

4. The success of cutting heavily oiled plants as a technique for reducing long-term damage to them depends upon a combination of factors, including the biology of the contaminated species, the elapsed time between contamination and cutting, the season in which cutting is performed, and the characteristics of the oil.

5. Cutting soon after contamination was beneficial. This treatment apparently reduced long-term damage to the most heavily oiled marsh grasses of the species *Spartina alterniflora*, despite the fact that it entailed trampling them. The foot traffic itself was detrimental, in that it apparently contributed to severe bank erosion. The heavily trampled portions of the river bank became more susceptible to erosion by boat wakes and natural wave and current action. It cannot be concluded that foot traffic and cutting were sufficient in themselves to cause severe erosion.

SECTION 3

RECOMMENDATIONS

The following recommendations are based upon observations made in the course of this investigation. They constitute an approach to marsh cleanup that will minimize the potential for damage to marsh plants and to the affected shorelines. Where economic or other necessity dictates the use of cleanup procedures that may be more damaging to the marsh than those described below, the recommendations provided here may still help to establish priorities and minimize the adverse impacts of cleanup.

It should be noted that these recommendations are applicable only where the contaminating oil is relatively viscous and functionally nontoxic. Most heavy fuel oils and some weathered crudes fall within this class. Diesel and other light fuel oils do not. These recommendations are also primarily applicable to estuaries on the northeastern Atlantic coastline of the United States. However, they are likely to be of some use wherever Spartina alterniflora and Phragmites communis are dominant components of an oil-contaminated salt marsh ecosystem.

1. As soon as possible after contamination, an oil spill response team should determine which portions of marsh are so heavily oiled that root suffocation of marsh grasses is likely to occur. Local or regional experts are best relied upon to provide this information. If such persons are not available, it may be necessary to use the general rule that completely oil-coated plants are in danger of suffocating, while plants with any appreciable portion of their green tissue exposed to the air are less subject to this form of mortality.

2. Initial cleanup should consist of low-impact methods, such as low-pressure flushing, to remove free oil from the marsh plants and substrate. The heavily oiled plants that are in danger of dying from root suffocation should be treated first. Some stands of marsh grass may be exposed to extensive natural flushing at tidal flow and ebb. This natural cleansing process may eliminate the need for flushing by the cleanup crews.

3. Immediately after initial cleanup those plants that remain heavily oiled, and whose roots are still in danger of suffocating must be treated in some way that will expose their internal tissues to the atmosphere. The most common treatments are cutting and burning. Cutting may be an effective treatment for many species, but it can only be recommended for Spartina alterniflora on the basis of this study.

4. Manual cutting of oiled plants in shoreline areas exposed to high wave and current energy should be employed only after other methods have been explored and rejected. Methods that eliminate, or at least minimize foot traffic on the river bank are highly preferred. Possible alternatives include use of aquatic vegetation cutters and controlled burning.

A few additional recommendations, related to but not necessarily arising from this investigation, are relevant to possible future studies:

5. Continue qualitative monitoring of erosion and plant growth along the cut and uncut contaminated regions on the Hackensack River bank. This will help to elucidate the long-term effects of either cutting or of taking no action on bank stability.

6. Conduct studies that will determine the suitability of cutting, not cutting, or using innovative (no foot traffic) removal techniques for more toxic oils.

7. Use the quantitative data provided in this study to aid in the sampling design of future studies in the Hackensack Meadowlands or similar regions of the northeastern United States.

8. Develop contingency plans for oil spills that will make optimal use of all available decontamination facilities and knowledgeable persons in the immediate vicinity and the region at large.

SECTION 4

STUDY RATIONALE AND METHODOLOGY

The stated objective of the investigation described in this report was to "conduct a variety of studies designed to supplement, expand, and verify aspects of the ongoing study (EPA 68-03-2160) regarding development of state-of-the-art procedures for protection, cleanup, and restoration of marshlands endangered by oil spills. Particular emphasis [was] to be given to evaluation of the impacts and effectiveness of the cutting techniques used in cleanup" (EPA, 1976).

To accomplish these goals in the context of the Wellen spill and subsequent contamination of the Hackensack Meadowlands, it was necessary to determine the effects of the spilled oil on the marsh flora and fauna, the biotic effects of the cutting operations, and any additional effects that might arise when cutting and oiling occur together.

POTENTIAL IMPACTS OF SPILL AND CLEANUP

Effects of Oil

The direct effects of oil on marsh plants and animals may be physical or toxic. Physical effects result from the viscous and adhesive properties of oil. Stomata (gas-exchange pores) of plants may be blocked. The gills and mouth parts of invertebrates may become clogged; the fine structure of birds' feathers may be disrupted, preventing flight and reducing or eliminating the insulative protection that the feathers provide. Crapp (1971) has summarized the physical effects of oils as those that act "by smothering organisms and cutting off respiratory exchange, and by interfering with their movement. . ."

Toxic effects result from the oil's interaction with the biochemical functioning of contaminated organisms. Baker (1971a) has discussed a few hypothetical mechanisms of toxic action on plants. The most general of these is the replacement of fatty molecules in cellular membranes, resulting in membrane disruption, increased permeability, and leakage of cellular contents. Increase in respiration is often observed, possibly because mitochondria (the organelles responsible for aerobic respiration) are damaged so that the rate of oxygen use is no longer coupled to other biochemical processes.

Effects of Cutting

Most grasses, including the familiar species used for lawn plantings, are not adversely affected by cutting. This is because the growth tissue, or meristem, is near the base of the plant. However, the response of some species may depend upon the time of year, meteorological conditions, and tides. Phragmites communis is one such species. While cutting may not directly injure the plant, tides that submerge the cut stubble prevent air from reaching the roots. If reduced aeration occurs in late summer, it can seriously impair the underground formation of new buds (Haslam, 1970). Furthermore, although buds develop throughout the year, they emerge from the ground to form aerial shoots only during a relatively brief period in spring. They remain dormant throughout the rest of the year unless the Phragmites stand is burned or the rhizomes (underground stems) are cut. Cutting the aerial stems does not interrupt the buds' dormancy. Consequently, no new stems replace those that have been removed. If cutting is performed directly after all the new shoots have grown to maturity (e.g., in July), the plants will be unable to photosynthesize for a large portion of the growing season. This can be seriously detrimental to the stand (Haslam, 1968).

No such adverse effects of cutting have been reported for Spartina alterniflora. Waisel (1972) has noted that repeated mowing of this species has been observed to stimulate growth and to promote uniform growth, high plant density, and early flowering.

Some methods of cutting vegetation involve heavy traffic on the marsh soil. This can result in trampled buds and remaining aerial shoots of the plants, disrupted substrate, broken portions of underground stems, and, ultimately, increased soil erosion.

Synergistic Effects

Additional phenomena not found in either an oil spill or a cutting incident alone may appear when both of these occur together. For example, oils can travel in the intercellular spaces of uncut plants, but they rarely enter the vascular (liquid transport) system. When plants are cut, however, oil may enter the vascular system via the cut stem, thereby gaining easier access to remote portions of the plant (Baker, 1971a).

Another synergistic effect may occur if oil is trampled into the marsh sediments. These sediments are frequently anaerobic, a condition that inhibits the biochemical degradation of oil (Burns and Teal, 1971). Therefore, undecomposed oil may reside in the marsh substrate for a long time.

RATIONALE FOR DATA COLLECTION

Eleven sampling stations were selected, and certain features of each station were monitored during four sample periods. Data were gathered on: (1) composition and growth of the vegetation, (2) composition of soil invertebrate populations, (3) presence of oil at various depths in the sediments, and (4) erosion of the substrate. The reasons for selecting these characteristics for sampling are discussed below.

Vegetation

In any study seeking to examine the implications of a potentially damaging event on a given ecosystem, first consideration should be given to the onsite vegetation. Plants are the only organisms that trap the energy coming to earth from the sun. Therefore, all other organisms must ultimately obtain their energy from plants. Though few organisms graze directly on marsh grasses, as the grasses decay they are physically and chemically reduced to forms that other animals can use. These animals include shellfish larvae and fish fry ultimately consumed by humans. Marsh plants are also of great importance before they die and decay. They provide cover for wildlife, and the cushioning effect of their aerial parts and the binding character of their roots slow the erosive processes that would wash the marsh sediments away.

Soil Fauna

Just as vegetation is an indicator of the quantity of energy available to the salt marsh ecosystem, so animals can serve as sensitive indicators of the quality of that system. Soil animals display different responses to the presence of foreign materials. Some benthic organisms, for example, thrive on the nutrient-enriched sediments near a sewage outfall, while others cannot survive the high concentration of organic wastes (Patrick, 1950). Oil pollution may produce similar results.

The distribution of species in a sample is as important for providing insights into the quality of the estuarine environment as are the specific kinds of animals present. The few organisms that can live in polluted waters are likely to be more abundant than any one organism would be where no contaminant is present. The total number of benthic invertebrates is also an important indicator of the quality of marsh life because they provide the food for vertebrates such as fish and wading birds.

Oil in Substrate

There were two reasons for attempting to determine if oil were present in the substrate at each sample station. The primary reason was to provide evidence of causality if severe effects on the soil invertebrates or the marsh plants were observed. The secondary reason was to determine how long the oil remained in undegraded form in the substrate. This would be particularly important where the cleanup crews cut the marsh grasses and trampled oil into the soil. It is generally believed that burial of oil in anaerobic substrate prevents or greatly slows its degradation. The buried oil can then exert its detrimental effects on plant roots and benthic invertebrates for a long time after the original contamination.

Erosion

The effects of erosion may be more noticeable to people than any other impact of an oil spill and cleanup. Once a river bank erodes, it is no longer available for colonization by marsh plants. The biological productivity that was once associated with the eroded region is permanently lost. Erosion also adds particulate matter to the flowing water, reducing its quality for use by humans and aquatic organisms. This particulate material is likely to be dropped somewhere downstream, aggravating sedimentation problems and necessitating more frequent dredging, with additional environmental and economic costs.

LOCATION OF SAMPLE STATIONS

Figure 6 depicts the location of the eleven stations where physical and biological data were gathered during this investigation. The sampling sites were visited four times throughout the year following the spill: in July 1976, October 1976, March 1977, and July 1977. A sampling visit was originally planned for the winter of 1976-1977 but was cancelled because severe icing would have rendered data collection impossible.

Physical and Biological Attributes of the Sample Stations

Five sites were selected to evaluate the impact of oil and cutting operations on the marsh substrate and plants of the river bank. Stations 1, 2, and 5 were all located directly on the main channel of the Hackensack River. Stations 3 and 4 were located respectively on the north and south banks of a tributary east of the river. It would have been preferable to situate all of these stations on the main river channel, but it was necessary to sample some unoiled areas. These were found only along tributaries (see Figure 4).

The sites for four sampling stations were subjectively selected to be similar in terms of the elevation and shape of the bank, which was quite steep. Station 1 was positioned in a segment of *Phragmites* marsh on the river bank that had been oiled but not cut; it was therefore suitable for examining the effects of oil contamination in the absence of cutting. Station 2 was established in a region that had been oiled and cut. This station, like the rest of the cut region, supported a mixture of *Phragmites* and *Spartina*. It was not possible to measure the relative abundance of these species before cleanup operations were completed. Station 3, also dominated by *Phragmites*, served as an overall control site, being neither oiled nor cut. Finally, the unoiled *Phragmites* plants at Station 4 were cut by the research team so that the impacts of cutting could be observed in the absence of oil contamination.

At sample station number 5, on the inside of a bend in the river, the bank assumed the gradual slope characteristic of such locations, where the current slows and the water drops its sediment. This site supported a heavily oiled stand of *Spartina alterniflora*, and it was selected because it permitted the effects of severe contamination on this prominent marsh plant to be observed.

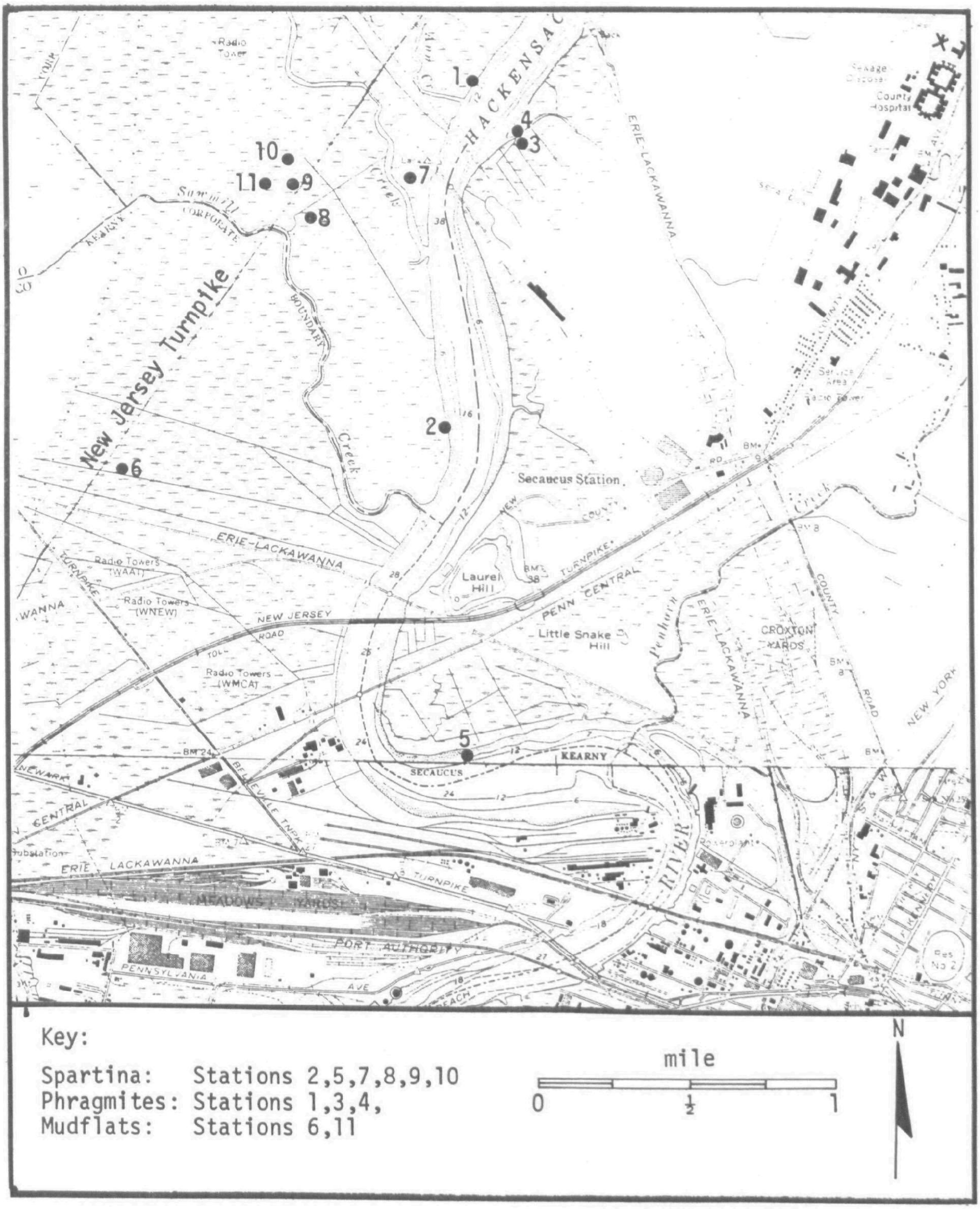


Figure 6. Location of Sampling Stations

No vegetation was cut in the inner or back marsh of the Kingsland-Sawmill Creeks area. Four stations, all dominated by Spartina alterniflora, were established there: two on the east and two on the west side of the New Jersey Turnpike. The tidal flows are restricted by the Turnpike; therefore, the vegetation on each side is subjected to differing flushing characteristics.

Although the oil penetrated almost everywhere in the back marsh, a few regions were protected. Station 9, west of the Turnpike, was protected by the Turnpike on one side, by a gas pipeline on the opposite side, and by embankments and substantial expanses of marsh grass on either end. This grass apparently served to trap most of the oil before it reached the sample station, for no signs of contamination were visible at the first sampling period. Station 7, east of the Turnpike, was similarly protected by a berm and extensive marsh.

The two other vegetation sampling stations, numbers 8 and 10, were located adjacent to channels on the east and west side, respectively, of the New Jersey Turnpike. Both had been oiled, but the contamination was no longer extensive by the time the research team arrived. Apparently, most locations in the back marsh had been exposed to a substantial amount of back-and-forth tidal flushing that helped clean the marsh grasses.

Two additional stations were established on the mudflats to observe penetration of the spilled oil into the sediments and to sample the invertebrate fauna for possible response to the spill. Station 6 was located in the east and Station 11 on the west side of the New Jersey Turnpike.

Table 1 summarizes the characteristics of the sampling stations.

TABLE 1. SUMMARY OF SAMPLE STATIONS

	Stations										
	1	2	3	4	5	6	7	8	9	10	11
Treatments											
Oiled	o	o			o	o		o		o	o
Cut		o		o							
Type	P	S&P	P	P	S	M	S	S	S	S	M
Location	R	R	R	R	R	E	E	E	W	W	W

Key: P = Phragmites marsh
S = Spartina marsh
M = Mudflats
R = River bank
E = Back marsh east of Turnpike
W = Back marsh west of Turnpike

SAMPLING PROCEDURE

Data were collected during four sampling sessions: in July 1976; October 1976; March 1977; and July 1977. The following paragraphs describe the data-collection procedures followed at each sampling period.

Vegetational Distribution and Productivity

During the initial sampling period, a transect was established parallel to the adjacent river or tributary stream channel at each of the 9 sample stations that supported vegetation. The position of the initial point of the transect in relation to the station marker and the transect's direction were recorded. Each transect was subjectively positioned so that all points along its length would be equally exposed to tides. Samples were taken in five 1-meter-square quadrats at 3.05-meter (10-foot) intervals along the transect. For a few of these sample plots, this nominal interval was adjusted to avoid significant irregularities in bank conformation like drainage sloughs and similar features. The sampling arrangement is depicted in Figure 7.

The location of each quadrat was recorded so that the quadrats could be re-established by use of measuring tape and pocket transit at subsequent sampling periods. After the winter, when investigators were confident that markers would remain stable, the boundaries of each quadrat were delineated with stakes and twine. This considerably expedited and improved the accuracy of quadrat re-establishment in the final sampling period.

The complexity of the terrain and the consequent difficulty of establishing similar sampling sites dictated the use of nondestructive sampling techniques. The investigators measured percent cover, stem density, stem height, and stem diameter of grasses at each sample station. Where the marsh grasses were short enough, the percent of ground surface area covered by each species was determined with a sampling frame. Elsewhere, it was necessary to estimate this quantity. The estimation was simplified and probably improved by placing 2 meter sticks so that each quadrat was divided into four 1/4-square-meter subplots. Each of these smaller units could be visualized more easily than the entire quadrat. Percentages of cover for each quarter-quadrat were estimated, summed, and divided by 4 to obtain the final estimate for the entire quadrat.

Stem densities were determined by counting the number of stems in 2 of the 1/4-square-meter subunits of each quadrat, resulting in 10 measurements per station per sample period. All shoots arising independently from the soil were counted as separate stems, whether or not they were attached to the same parent plant or not. Some problems are associated with this method of single-plant identification, as Caldwell (1957) has discussed. Nonetheless, the rest of the sampling procedure was designed around it. The ultimate goal was to obtain various indicators and measures of plant productivity within the quadrats, not to measure the size of individual plants, so this approach appears entirely justified.

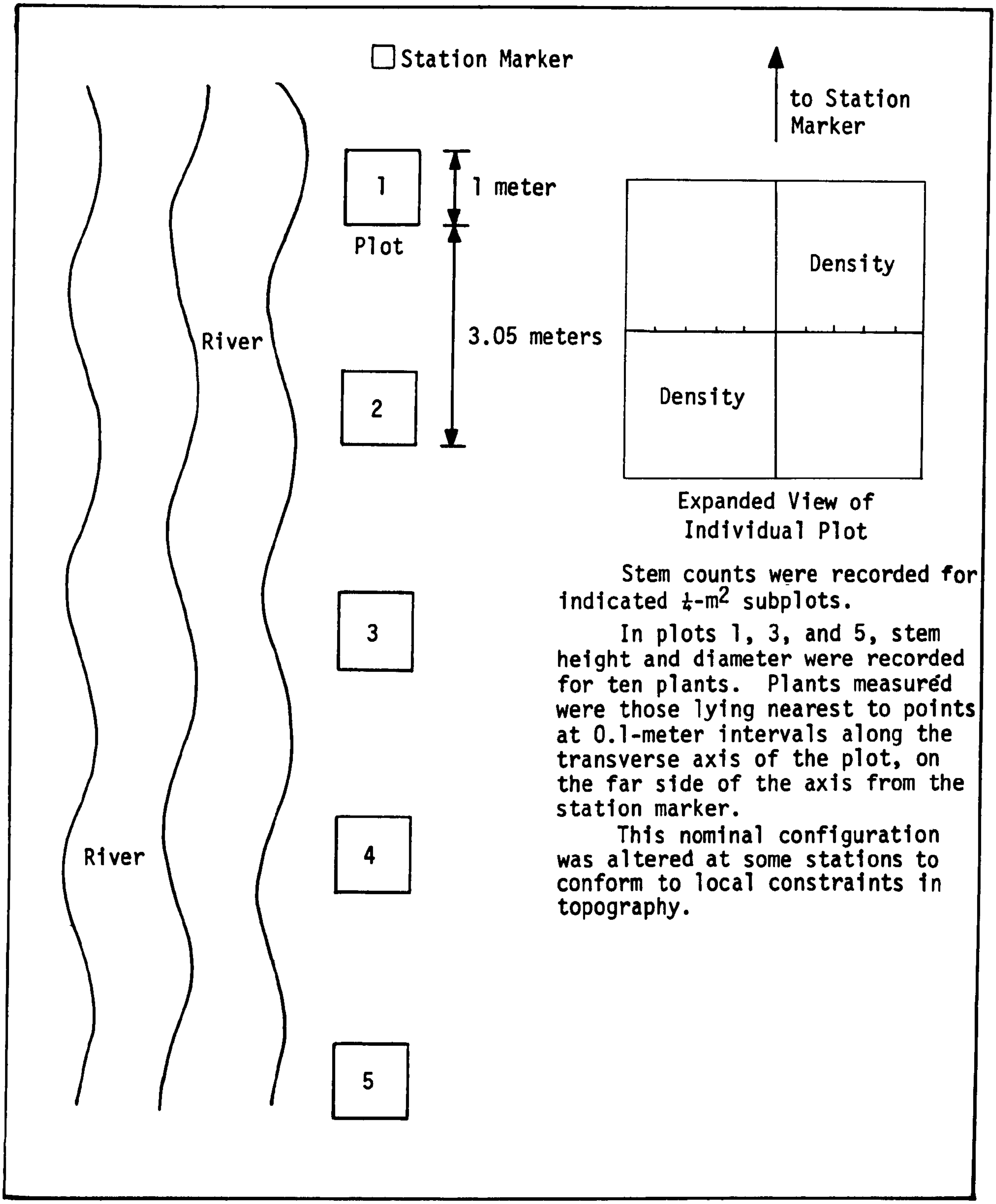


Figure 7. Configuration of Vegetational Sampling Stations

In the first, third, and fifth quadrats at each station, the height and diameter of individual grass stems were recorded for 10 plants. The plants selected were those lying nearest to points at 0.1-meter intervals along the transverse axis of the sample plot, on the far side of the axis from the station marker. Occasionally, there were not enough stems in appropriate locations; in such cases, other stems in or very near the quadrat, along the transect, were measured. Height was measured with a meter stick, to the tip of the longest leaves in *Spartina*, and to the tip of the most recently developed, unopened leaf at the apex of *Phragmites* stems. Stem diameter was measured with a micrometer-caliper.

The simplest assumption for calculating the volumes of the plants was to treat them as if they were cone-shaped, and to use the following formula:

$$\text{Stem volume} = \frac{\pi \times (\text{Height}) \times (\text{Diameter})^2}{12}$$

By taking the average volume of the stems in a given quadrat and multiplying it by the number of stems in that quadrat, a figure was obtained that estimated the total volume of vegetation in the plot. If it is assumed that volume of the plants is proportional to dry weight, this figure is an indicator of the biological productivity (fixed biomass) of the plot. Despite inaccuracies that may arise from some of the above assumptions, this estimate was useful because it permitted meaningful comparison of any 2 sample plots, whatever their dominant species. This is not true of stem height, diameter, or density, which are likely to differ between species. Although estimations of percent cover permit some comparison of the amount of light used by plants in the different quadrats, they fail to incorporate potentially significant differences in plant height.

In addition to the measurements described above, false-color infrared and true color aerial photographs were taken at each sample period. This program was intended to document any extensive plant mortalities that might have resulted from the spill.

Fauna

At each station, 5 samples of marsh soil were collected by hand, using a small, metal container. Care was taken to sample the same surface area at each location, but the depth of marsh soil collected varied where roots and rhizomes interfered with sampling. The samples were washed free of sediment in a 2-millimeter wire mesh and preserved in 10 percent buffered formalin solution. Selected samples were shipped to a biological laboratory after each sampling period for identification of all invertebrate fauna.

Interviews with knowledgeable persons furnished some information on the apparent response of birds and other prominent marshland species to the oil spill.

Distribution of Oil in the Substrate

Duplicate marsh soil cores were collected at each sample station, with a stainless steel corer. The core samples were placed in airtight plastic bags, wrapped in aluminum foil, and frozen in dry ice immediately after collection.

Selected samples, from 2.5, 5.0, and 7.5 centimeters depth in the marsh soil, were sent to a laboratory for chemical analysis. It was originally hoped that gas chromotography (GC) could be used to identify the oil and estimate its concentration in the marsh substrate. Unfortunately, GC analyses that were performed after the first sampling period produced no clear-cut results. Thin-layer chromatography (TLC) was subsequently used as the analytic technique. TLC is less sensitive than GC, but it permits rapid screening of a large number of samples without entailing excessive costs. No true reference material (Wellen No. 6) was available when the current investigation was initiated. It was hoped that internal comparisons of the sample stations would indicate the presence or absence of oil at any given station. Comparison was also made to a sample of oiled gravel. This sample was free of organic sediments that would appear as peaks in the chromatogram and mask the oil's presence.

Erosion

Erosional data were collected at all vegetated sample stations. Two wooden stakes, one closer to the marsh interior and one nearer the adjacent water body, were marked, notched, and placed in the soil at measured distances and directions from the station marker. At each sample period, the height of the notch on each stake was measured. These data provided a continuing record of the elevation of the marsh soil surface. This permitted monitoring for sediment loss that might accompany the death of marsh vegetation in oiled areas and the heavy foot traffic in cut regions.

Distances were also measured from the marker stakes to the major break in slope at the erosional face of the river bank at Stations 1 through 5.

The aerial photographs taken as a portion of the vegetational sampling program were also intended to extend the observations of erosion processes beyond the individual stations where measurements were made. Additional, qualitative data were gathered on other factors that could potentially affect erosion. These included tidal flow, boat traffic, bank conformation, and general substrate characteristics.

SECTION 5

RESULTS

All results are presented in figures or tables in the Appendix. For convenience to the reader, selected data are also presented in the text.

VEGETATION

The data on vegetational characteristics of each sample station are displayed in Figures A-1 through A-6 and in Tables A-1 and A-2.

Figure 8, "Total Plant Volume per Unit Area" shows the pattern of standing vegetational crop throughout the year of study. The initially large amount of plant material present in July 1976 decreased in October because of dieback and decay. This effect is more pronounced in Spartina, whose stems are softer, more pliable, and more susceptible to the elements, than are Phragmites stems. The data collection in March did not include dead stems from the previous year's growth. The volume of vegetation in that month represents the small shoots of the new growing season. In July 1977, the amount of plant material present is similar to what it was the previous year.

The data suggest that there is less Phragmites at Station 1 in 1977 than in 1976. While it might at first be surmised that this was caused by oil contamination, this is probably not the case. At the final sampling period, the charred remains of marker stakes and other debris provided convincing evidence that a fire had destroyed the surface vegetation at the station. As discussed in Section 2, fire breaks the dormancy of Phragmites buds. The stems measured in July 1977 had resprouted, but had not as many dormant buds nor the same time to grow as the previous year's stems.

The control Phragmites at Station 3 seem to have grown back quite vigorously in 1977. Interestingly, the plants at Station 4, which were experimentally cut, recovered only as much as those at Station 1, even though Station 4 appeared similar to Station 3 at the study's outset.

The Spartina controls (Stations 7 and 9) grew back extraordinarily well by July 1977. The apparently spectacular increase at Station 9 might, however, have resulted from the station marker's being lost over the winter. The transect may have been re-established in a slightly different location, resulting in misleading data. Nonetheless, the marsh surrounding Station 9 was uniform in appearance, so the data reported here are probably representative of the original transect.

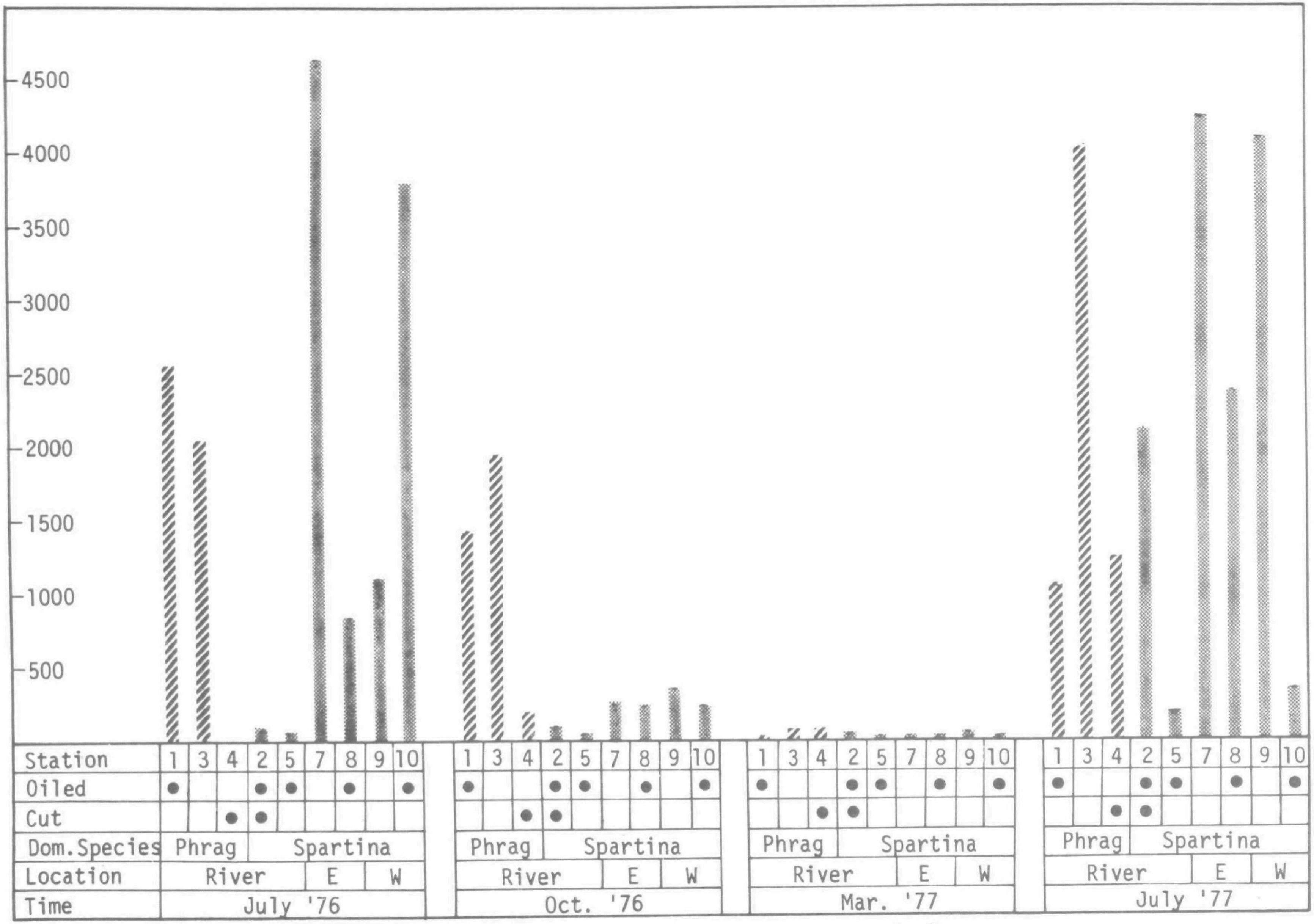


Figure 8. Total Plant Volume Per Unit Area (cm^3/m^2)

The data suggest that the uncut, oiled Spartina to the west of the New Jersey Turnpike (Station 10) did not grow well. The decrease may reflect a loss of substrate rather than poor plant growth, since it appeared that there was less available substrate for Spartina after the winter of 1976-1977, and since Spartina grew very well at Station 10 wherever there was available substrate. This observation is supported by 2 groups of data. First, the percent cover (see Figure A-1) was not much lower than at other stations. The tall grass stems there leaned over and covered unvegetated portions of the sample plots. Second, the stem density (Figure A-2) compares favorably with that at other stations in July 1977, despite the paucity of substrate at Station 10.

The uncut, oiled Spartina in the back marsh east of the New Jersey Turnpike (Station 8) exhibited good growth by the final sampling period, although not as good as the control Spartina. The soil at Station 8 was very moist. The ground contained many poorly drained depressions.

The oiled, cut plants at Station 2 grew to approximately the same total volume as the Spartina at Station 8 in July 1977. They did not produce as much as did the control Phragmites at Station 3, but exceeded the concurrent production of Phragmites at Stations 1 and 4.

First-year (1976) measurements at Station 5 were taken on the young shoots that had started to replace the contaminated Spartina stems when this study was initiated. No measurements of the oiled mass of dead vegetation was possible at that time. However, the second-year productivity of the Spartina at Station 5 was unquestionably lower.

The data on stem height, stem density, individual stem volume, and percent cover all support the data on total plant volume. Station 5 consistently appears less productive than the others. Stem diameter does not appear to vary much.

Note that the density of Phragmites stems is roughly the same at the first and final samplings. The experimental cut (Station 4) appears to have been somewhat less dense initially. Perhaps some stubble was trampled into the soil. Note also the higher density of Spartina, reflecting its smaller size and tendency to sprout year-round.

A few additional observations are relevant to the response of the marshland vegetation. The earliest cut stands of oiled Spartina displayed good growback of vegetation by July 1977. Station 2 was one such region. However, the upriver portion of the cut zone, which was cut more than two weeks after the spill, exhibited a less positive response. Oiled, uncut regions like Station 5 displayed poor growth in 1977.

No extensive plant mortality was observed in any aerial photographs. Except for oiled, uncut stands on the riverbank, none was observed from the ground.

Weathered oil, presumably from other spill events, was observed in some locations, but not at any sampling stations. At the final sampling period, oil from a small, recent spill was observed at Station 5 and along the west bank of the Hackensack River north of Station 5.

FAUNA

Donald Smith (personal communication) has reported that a number of bird species that usually nest in the Hackensack Meadowlands were rare or absent in 1976 after the marshes were contaminated by spilled oil. However, by the following year, populations were apparently back to normal and thriving. Several pairs of glossy ibis (*Plegadis falcinellus*), a species never observed nesting in the Hackensack Meadowlands before, were observed and strongly suspected of breeding there in the Spring of 1977.

Smith also noted that, after the spill, marsh and red-jointed fiddler crabs (*Uca pugnax*, *U. minax*) and diamondback terrapin (*Malaclemys terrapin*) were physically handicapped by contamination with tarry residues from the oil. Nonetheless, these creatures continued to attempt movement. They did not appear to be poisoned, as they might have upon exposure to a truly toxic oil. One other unusual effect was the appearance of mating coloration and display in male fiddler crabs in October 1976, well past the usual mating season (Donald Smith, personal communication).

The data on marsh soil invertebrates are presented in Tables A-3 and A-4. Data include the habitat conditions, populations of various taxa, number of genera, number of individuals, and Shannon-Weaver diversity index for each sampled station. The population levels in 1977 were generally lower than those in 1976. The populations of oligochaete worms were observed to be higher than that of other taxa in most samples. In the first and second samplings, the lowest species diversity was found at those stations where the vegetation had most recently been cut in 1976, i.e., Station 2 in July, and Station 4 in October. Calculated diversity indices, dependent to a degree upon population size, were lower in the final two samplings.

No organisms were observed at the oiled mudflat station, number 6 during the first July sampling. It could be argued that this was an effect of the oil. However, since other oiled stations (e.g., 1 and 2) displayed substantial populations, it was felt that some other effect (perhaps toxic runoff from the New Jersey Turnpike) was being observed. The mudflat stations were subsequently abandoned and Stations 7 and 8 were substituted in subsequent sampling sessions.

OIL IN THE SUBSTRATE

Internal comparison of the thin-layer chromatograms derived from soil cores at selected sample stations revealed several points of similarity among the organic compounds in the substrate at each station. However, these were apparently of biogenic origin, because they bore no similarity to the oil in the gravel sample which served as a reference in this analysis. Possible interpretations of these negative results are discussed in Section 6.

EROSION

Observed interim and net changes in elevation of the marsh surface are shown in Table A-5. A net loss of soil is indicated by most river bank data, and a net gain is suggested by data from the marsh interior. These observed changes may be due in part to sinking of marker stakes or isostatic adjustments in the marsh surface.

Apparent sediment accretion is most widely observed between the first and second samplings. The predominantly negative changes between the second and third sample periods may reflect marsh sediment compaction associated with heavy winter ice loading. The final data suggest little change.

Table A-6 displays distances to the erosional face in river bank areas. These are presented graphically in Figure 9. Note that the intervals between sample periods are not equal. No substantial difference is suggested by the data for uncut, oiled area (Station 1) or uncut and experimentally cut, unoiled areas (Stations 3 and 4). In contrast, a radically different rate of erosion between the first and second sampling occurred at Station 2. This station was exposed to both oil and heavy manual cutting operations. Aerial photographs and ground observation confirmed that this extreme bank erosion had occurred along much of the riverbank where the oiled plants had been cut. Furthermore, the severe erosion was restricted to the cut regions.

The mechanism of erosion in this case was bank undercutting followed by slumping. Many private and commercial boats and ships were observed on the Hackensack River during all sampling periods. The wakes produced by this traffic were sufficient to have provided the primary erosional force. The surficial mat of Spartina roots remained essentially intact and continued to support growing plants throughout the investigation. The riverbank at Station 2 resembled that at Stations 1, 3, and 4, and consisted of a current- and wave-cut escarpment. The riverbank in the less severely eroded parts of the cut zone was not so steeply sloped.

Station 5, unlike the other sites on the Hackensack River bank, showed a net increase of distance to the break in slope at the bank's edge.

Examination of aerial photographs and ground observation yielded the impression that erosion of a different type had occurred along the later-cut portions of the riverbank. In these locations, soil appeared to have been lost from the surface of the bank. This condition was noticed after the winter of 1976-1977.

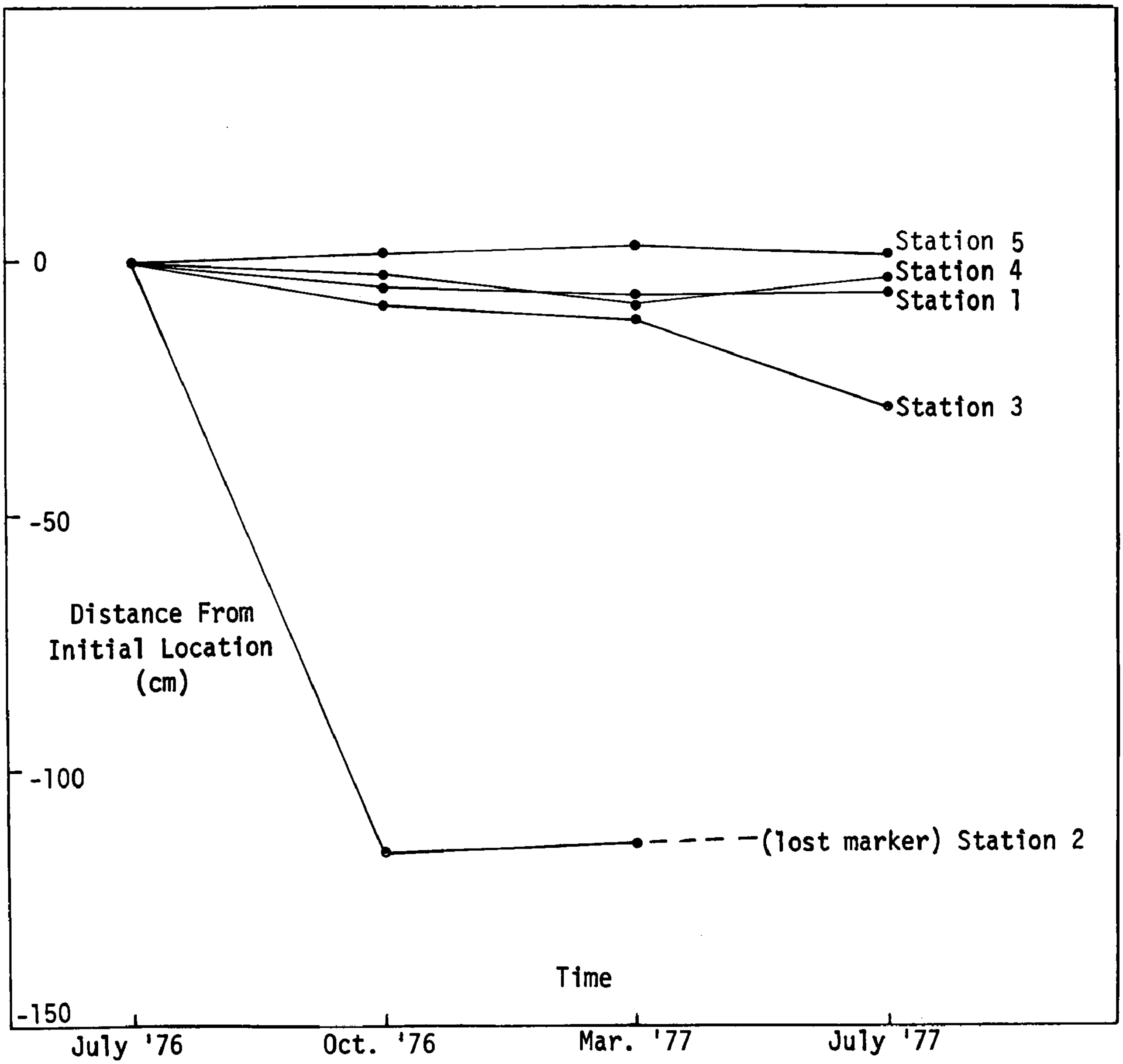


Figure 9. Position of Bank Edge Vs. Time

SECTION 6

DISCUSSION

All oil spills are different in some respects. The findings reported in the present study are applicable only to spills where a similar type of relatively viscous, heavy fraction oil is spilled in a similar estuarine environment. However, since such oils are frequently spilled, the results presented herein are likely to have wide applicability.

Patterns of tidal flow that distribute spilled oil also partly determine the ecological characteristics of the affected region. Thus, areas isolated from contamination may not be directly comparable to oiled regions. For instance, the vigorous growth of *Spartina* at Stations 7 and 9 in the final sampling may result more from their locations away from open water than from the fact that they weren't oiled. The present study affords no purely objective way of distinguishing among these possibilities. The author's own impression is that the difference is locational.

Because the sample sizes were rather small and the data quite variable, the quantitative results reported here should be considered indicative and supportive only of observations made in text, not as conclusive evidence. Nonetheless, considerable use can and should be made of these data in the design of future studies, because they provide estimates of the variability of the sampled material. These estimates are extremely useful in determining the optimal sample size, sampling design and the probability of obtaining meaningful results within given cost constraints.

Finally, it should be emphasized that no detailed quantitative baseline data were available for this study. A similar difficulty is likely to plague many future attempts at determining the effects of any large-scale impact upon an ecosystem.

SOURCES OF ERROR

The most prominent sources of error in the present study have been uncontrolled variables. Sampling sites were selected to be as similar as possible, but it was apparent from the start that the stations were not precisely equivalent.

The vegetation data are extremely variable. The standard deviations (displayed as dark lines superimposed on the histogram bars in Figures A-1 through A-6) are generally large, compared to the mean value (length of the bar) of any given measurement. This variability could be a result of the small number of samples used in this study; more likely it results from the clumping of data. Clumping simply means that observed characteristics are not independent. For example, if a sample contains one large stem, there is a greater-than-random chance that the next measured stem will be large. Data for such clumped distributions characteristically have a large standard deviation.

In the case of data on the percent cover and density, the clumping was caused by the physical clustering of Spartina and Phragmites plants. Spartina forms clones: small, young shoots arise from rhizomes (horizontal, underground stems) that sprout from a large parent stem. Caldwell (1957) has described this process in detail. To a lesser extent, Phragmites does the same. However, Phragmites is more evenly spaced, as evidenced by the smaller standard deviations in the Phragmites density (see Figure A-2).* Clumping also reflects the tendency of these and many other plant species to cluster in optimal microhabitats.

The clumped distribution of stem height and diameter results less directly from the physical clustering of the plants. Stems selected to be measured were those lying closest to certain points on a small transect that bisected each quadrat. If this transect failed to cut through clumps, a disproportionate number of small stems on the clump edges were measured. If the transect did pass through clumps, more large stems were measured.

The high variability in height and diameter is reflected in an even greater standard deviation of individual stem volume (Figure A-6). Limited resources and the rather lengthy calculations required prevented the determination of the standard deviation of total plant volume per square meter (Figure A-3). Nevertheless, it follows from the variability of stem height and diameter that the standard deviation of stem volume would have been quite large.

If it is assumed that the probability of selecting a cluster of large or small stems is approximately equal to the true proportion of large and small stems in the sample plot, then the calculated mean will be a much better estimate of the true mean stem size than the large standard deviation would imply. A similar argument holds true for percent cover and stem density.

The above assumption failed only in instances where the clumps were so sparse that a sample point was unlikely to fall in the center of one. In these cases, there probably was some bias towards sampling small stems. This bias would have accentuated measured differences between lushly and sparsely vegetated plots. However, except for Stations 8 and 10 in July 1977, sparse plots also had very open clumps, reducing the effects of the bias. The data are therefore considered reliable, though interpreted cautiously.

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*The very large standard deviation of Phragmites density at Station 1 in July 1976, is the result of using a 1-square-decimeter quadrat for counting densities. On the basis of this sample, this quadrat size was judged to be too small, and 1/4-square-meter quadrats were subsequently adopted.

VEGETATION

Most of the oiled, uncut sample stations have been affected in some way besides oiling that clouds the interpretation of data. Station 1 was burned; Station 8 and Station 10 were characterized by irregular substrate that affected the distribution of the plants. It is possible that the low productivities observed in July 1977 at all these sites are due to oil. The following paragraph offers evidence that at Stations 8 and 10 the differences were due at least in part to habitat.

Explanations for the loss of substrate at Station 10 were suggested by a few observations. The station was heavily trafficked by fishermen. Furthermore, the station's location between 2 embankments might have encouraged excessive scouring by ice. The recorded heights of plants at Station 10 (Figure A-4) are not great. It is believed that the bias discussed above is responsible for the low recorded stem heights. This would also ultimately contribute to low total volume. Station 8 contained many poorly-drained portions of marsh. As Shea et al. (1975) have discussed, the Spartina in such regions often grows in depauperate stands. Station 8 was no exception. Some of the sample plots were sparsely vegetated. Yet, even where the vegetation was sparse, many individual clumps of grass were quite healthy. Thus, Station 8 was exposed to the same type of bias as Station 10, but to a lesser degree.

On the other hand, the low productivity at Station 5 was probably a direct effect of the oil spill. The poor response of the vegetation is reflected in all the parameters that were measured. Clumps at this station were not well-developed, and the taller stems in their interiors were included in many of the samples. Furthermore, the oiled remains of marsh grasses growing prior to the spill were still present in July 1976. These grasses appeared to be much more abundant than those which grew in 1977, although it is difficult to judge the volume of heavily oiled and matted vegetation accurately.

The additional contamination (source unknown) observed at the final sampling suggests that oil is frequently carried by the extant current regime to the same collecting points, causing chronic pollution. It is possible that the poor growth at Station 5 partly results from continual oiling over many years, not just from the Wellen spill. Chronic contamination can be much more damaging than a single incident (Baker, 1971b).

Very little Phragmites was present at Station 2 in July 1977. Perhaps this species never comprised a major component of the vegetation at this site. It is also possible that cutting favored the Spartina and damaged the Phragmites in what was once more of a mixed stand, as discussed in Section 4.

Good recovery of Spartina was observed at Station 2, where the vegetation was oiled and cut. Farther upriver the oiled, cut grass did not grow so well. These latter plants were cut later than the others, however. Mattson et al. (1977) concluded that the oil plugged the stomata of the Spartina plants, thus depriving their roots of air (see Section 2). The roots of the earliest-cut plants were saved from suffocation when the cutting operations opened the plant stems, allowing air to diffuse downward. Approximately 2 weeks after the initial oiling, the remaining contaminated roots of *Spartina* started to die for want of oxygen; thus, later cutting was less effective in promoting recovery.

The results of the present study support the conclusions of Mattson et al. (1977). In areas that were oiled but where the plants were not completely coated (e.g., Station 1) or where tidal flushing washed plants partly clean (e.g., Stations 8 and 10), there is no conclusive evidence of oil damage. It therefore seems unlikely that the oil exerted its negative effects upon the marsh grasses through any toxic mechanism. Cutting was apparently an effective way of combatting the physical blockage by oil of the plants' gaseous exchange with the atmosphere. It was therefore desirable in this case.

Unfortunately, it cannot be generalized from this study that cutting is a panacea for oil damage to marsh plants. Other factors may be significant in other situations. Seasonal effects and the biology of the affected species must be considered. For example, it is possible that the apparent decrease in the standing crop of *Phragmites* at Station 4 was caused by the cutting that was performed when this study began (Section 4). Results might also differ for oils with higher concentration of toxic components. If toxic oils were trampled into the soil during cutting, they might persist indefinitely and preclude recolonization. Cutting might encourage migration of toxic materials down the stems to the roots and rhizomes of affected plants.

Possible alternatives to hand-cutting include use of aquatic vegetation cutters and burning. Both techniques minimize foot traffic on potentially sensitive marsh soil. Although ignition during the growing season may be difficult, burning has the added advantage of promoting sprouting in *Phragmites*. This technique would have to be used in the context of air quality and safety standards, as well as vegetational management options, since burning can alter the composition of marsh plant populations. Nonetheless, burning is probably the available technology most compatible with natural functioning and continued maximal productivity of the marsh.

FAUNA

The mating coloration and behavior of male fiddler crabs in October 1976 may have resulted from harmonal interference caused by petroleum hydrocarbons still leaching from the marsh soil at that time. This phenomenon, which was not observed in 1977, has been observed elsewhere (Charles Krebs, Saint Mary's College, personal communication).

It does not appear that the large vertebrates of the Hackensack Meadowlands, especially the birds, were adversely affected for longer than the season of the spill itself.

There is no clear correlation between any properties of the sampled invertebrate communities and the presence or absence of oiling. The dense population of oligochaete worms is typical of a highly organic substrate like that found in the Meadowlands. The lowered diversity index of fauna at cut stations may be an indication either of the direct effects of cutting and trampling on the marsh soil fauna or of the reduction in habitat diversity that accompanied the loss of the grasses. The lowered index may also have resulted from some other locational effect, or it may simply be an artifact of the small sample size. The interpretations offered here must therefore be considered tentative.

The lack of observed organisms at Station 3 in the third and fourth sample periods and the low diversity indices in 1977 probably reflect the generally low numbers of organisms present at that time. The harsh winter of 1976-1977 is a possible cause of the population reduction. It is not likely that unrecovered oil caused the decrease, since the oil spilled in the Hackensack River was apparently physically disabling but not toxic. Moreover, the population reduction is not related to the known distribution of the oil.

In retrospect, it is unfortunate that benthic monitoring was not continued at the mudflat Stations 6 and 11 after the first sample period. Station 11, which supported a variety of organisms, was only lightly oiled and therefore served as a control for the more heavily oiled Station 6. Even if toxic or other effects unrelated to oil contamination were present at Station 6, the site might normally have supported some invertebrates. The complete absence of organisms in samples collected at this station, however, forces speculation that oiling may have injured the soil fauna. A subsequent increase in invertebrates at Station 6 would have provided evidence in support of this conjecture, but no additional data were collected. Nevertheless, samples collected at this location at any time in the future would be of value in determining whether oil from the Wellen spill was injurious to the benthic organisms.

OIL IN SUBSTRATE

No correlation was established between the organic materials in the soil cores gathered at various sampling stations and the sample of oiled gravel that served as a reference. There is no question that the bulk of the oil in the gravel sample came from the Wellen spill. Therefore, although positive results might have been subject to dispute in the absence of a true reference, the negative results reported here must be considered as reliable as those that would have been obtained from an uncontaminated sample of the spilled oil.

There are several possible explanations for the observed lack of correlation. The sampled sediments may simply not have been oiled to a level that would have been detectable by TLC. Furthermore, highly viscous oils are unlikely to penetrate soil, especially a marsh soil composed of very fine sediment. In fact, the contaminating oil in this spill formed only a thin, tarry layer on the marsh soil surface at the locations where soil contamination was still apparent as of mid-July 1976. There was no indication of soil penetration.

It is interesting to note that the results indicate no soil contamination at Station 2, which was subjected to heavy foot traffic shortly after the spill. Perhaps the soil there was firm enough to prevent mixing of oil with any but the most unconsolidated upper layers of sediment. The surface sediment that was disturbed and heavily contaminated may have washed away during subsequent high tides.

A final possibility is that the oil which contaminated the gravel sample weathered differently from that which contaminated the marsh surface. However, it is unlikely that the decomposition processes could have been so different as to completely mask any similarity within 2 months after the spill, when the soil cores were first collected.

Further speculation is not warranted in the absence of more definitive data. Future studies should probably continue to use TLC as a screening procedure before more sophisticated and costly forms of analysis are used. However, such tests are more likely to be more successful if samples are containing a high concentration of the suspected contaminating oil are collected. For example, in this investigation, the upper few millimeters instead of the upper few centimeters of oiled marsh soil would have been collected and then compared with similar samples at greater depths in the soil.

EROSION

It is difficult to ignore the association between cutting and accelerated bank erosion at Station 2. Because the <u>Spartina</u> root mat remained undamaged, the erosion cannot be attributed to plant mortality. The pressure of heavy foot traffic may have been transmitted through the root mat to the unconsolidated soil below, resulting in destabilization. Although they may have been contributing factors, neither oiling nor exposure to the open river channel can be implicated as sole causes of erosion, since Station 1 was also both oiled and situated on the main river bank but it did not erode as much as Station 2.

The shape of the bank may have some effect on erosion potential. The northern portion of the cut region, where the bank slope was less steep than at Station 2, did not experience bank undercutting. However, the oiled plants on this portion of the bank were cut last. It is possible that foot traffic associated with cutting operations was less intensive toward the end of the cleanup effort.

The <u>Phragmites</u> at Station 4 was cut so that the effects of cutting in the absence of oil contamination could be observed. The lack of unoiled river frontage necessitated locating this station on an interior channel. The absence of erosion at this site may be attributed either to lack of oiling or to the low wave and current energy environment. The latter explanation appears more likely, since high-energy environments are known to cause erosion. It is also possible that the deeper root mat of *Phragmites* plants provides more bank stabilization than that of *Spartina*. This would be consistent with all observations.

The positive values observed at Station 5 probably reflect the sedimentological environment. This station is on the inside of a bend in the river, a natural point of accumulation.

The subjectively observed surface erosion in the later-cut regions was probably caused by winter icing and spring runoff through bank areas where the plant cover was no longer intact. There is no way to predict with certainty whether and to what degree this erosion might have been reduced had the plant cover been maintained at its original vigor.

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Table A-1

Measurements of Phragmites

Parameter Measured	Sample Period	Station No. 1 Mean	Station No. 1 Standard Deviation	Station No. 1 No. of Samples	Station No. 3 Mean	Station No. 3 Standard Deviation	Station No. 3 No. of Samples	Station No. 4* Mean	Station No. 4* Standard Deviation	Station No. 4* No. of Samples	Station No. 2 Mean	Station No. 2 Standard Deviation	Station No. 2 No. of Samples
% Cover	1	82	17.9	5	100	0	5	--	--	--	--	--	--
	2	58	12.3	4	84	15.2	5	30	39	5	1.8	2.9	5
	3	<.6	<.55	5	<1	--	5	<1	--	5	--	--	5
	4	54	36	5	96	6.5	5	56	30	5	5.2	5.6	5
Density (Stems/m^2)	1	146	242	15	120	51.9	10	70.4	26.5	10	--	--	--
	2	58.5	30.3	8	49.2	27.2	10	43.6	55.1	10	0	0	10
	3	6.8	8.7	10	31.2	12.5	10	23.2	16.4	10	11.2	11.4	10
	4	95.2	80.8	10	107.6	48.1	10	85.6	51.8	10	18.8	19.8	10
Height (Cm)	1	183	54.9	36	205.9	36.86	28	--	--	--	--	--	--
	2	181.7	44.0	25	234.8	43.58	29	67.3	32.6	28	5.2	2.76	2
	3	2.75	1.76	15	6.48	1.84	30	10.86	5.37	20	4.48	3.41	4
	4	103.3	52.6	28	198.2	38.3	29	127.2	66.1	30	86.1	0	1
Diameter (Cm)	1	.51	.24	36	.50	.18	28	.73	.24	29	--	--	--
	2	.674	.150	25	.759	.180	29	.442	.174	28	.436	.0817	2
	3	.461	.185	15	.810	.0384	30	.665	.266	24	.422	.0782	4
	4	.486	.271	28	.792	.208	29	.594	.199	30	.394	0	1
Stem Volume (Cm^3)	1	18	19	36	17	18	28	--	--	--	--	--	--
	2	24.4	14.2	25	39.7	26.1	29	4.41	4.10	28	.235	.0452	2
	3	.223	.270	15	1.3	.941	30	1.63	1.42	20	.239	.295	4
	4	10.9	15.4	28	37.5	24.5	29	15.5	17.2	30	3.49	0	1
Total Volume (Density x Stem Volume) (Cm^3)	1	2,570	--	--	2,040	--	--	--	--	--	--	--	--
	2	1,427	--	--	1,953	--	--	192	--	--	0	--	--
	3	1.5	--	--	40.6	--	--	37.8	--	--	2.7	--	--
	4	1,041	--	--	4,035	--	--	1,327	--	--	65.6	--	--

*Plot 4, sample period No. 2: the values for stem dimensions include plants not within sample plot. These differed very little from values using only within plot plants.

Table A-2

Measurements of Spartina

Parameter Measured	Sample Period	Station No. 2			Station No. 5			Station No. 7		
		Mean	Standard Deviation	No. of Samples	Mean	Standard Deviation	No. of Samples	Mean	Standard Deviation	No. of Samples
% Cover	1	18	9.8	5	--	--	--	95	7.1	5
	2	34	6.9	5	2.2	3.3	5	33	21.1	5
	3	<1	--	5	<.6	<.55	5	<1	--	5
	4	86	14.7	5	20	22	5	94	13	5
Density (Stems/m^2)	1	76.7	42.5	15	18	28.7	8	221	62.4	10
	2	367	356	10	27.6	65.1	10	349	79	10
	3	166	124	10	34	66.3	10	299	131	10
	4	397	170	10	146	235	10	554	240	10
Height (Cm)	1	20.8	9.42	30	10.3	6.13	19	94.1	75.5	30
	2	11.2	12.6	28	15.3	16.8	30	19.8	20.6	29
	3	3.92	1.86	26	3.62	1.86	10	5.46	2.39	29
	4	55.7	37.8	29	23.9	25	20	52.8	65.7	30
Diameter (Cm)	1	.35	.19	30	.51	.26	19	.68	.30	30
	2	.202	.0879	28	.285	.205	30	.228	.120	29
	3	.120	.260	26	.164	.0503	10	.0531	.0564	29
	4	.500	.235	29	.427	.213	20	.488	.251	30
Stem Volume (Cm^3)	1	1.0	1.4	30	1.2	1.8	19	21	25	30
	2	.207	.318	28	.865	1.69	30	.661	1.47	29
	3	.0135	.0259	26	.0256	.0150	10	.0351	.0311	29
	4	5.2	5.69	29	1.96	2.73	20	7.67	12.3	30
Total Volume (Density x Stem Volume) (Cm^3)	1	76.7	--	--	21.6	--	--	4,641	--	--
	2	76.0	--	--	239	--	--	231	--	--
	3	22.4	--	--	.9	--	--	6.9	--	--
	4	2,064	--	--	286	--		4,249	--	--

Table A-2

Measurements of Spartina (Cont.)

Parameter Measured	Sample Period	Station No. 8			Station No. 9			Station No. 10		
		Mean	Standard Deviation	No. of Samples	Mean	Standard Deviation	No. of Samples	Mean	Standard Deviation	No. of Samples
% Cover	1	64	39.8	5	74	31.5	5	82	32.1	5
	2	13	14.7	5	45	26.7	5	55	20.9	5
	3	<1	--	5	<1	--	5	<1	--	5
	4	87	20.0	5	63	24.8	5	57	27.0	5
Density (Stems/m^2)	1	62.6	54.6	10	117	70.8	10	255	109	8
	2	116	93	10	115	84.7	10	167	109	8
	3	83.1	113	10	119	184	10	84	113	10
	4	451	295	10	264	134	10	321	335	10
Height (Cm)	1	84.3	67.4	28	56.9	41.75	29	106.2	73.75	20
	2	36.5	33.7	29	49.8	32.06	30	44.7	23.7	20
	3	5.90	2.53	30	6.45	2.63	30	4.93	1.89	30
	4	36.4	53	30	88.8	65.1	30	23.7	29.7	30
Diameter (Cm)	1	.65	.19	28	.53	.29	29	.62	.21	20
	2	.390	.206	29	.412	.169	30	.316	.0953	20
	3	.224	.0780	30	.212	.0917	30	.154	.0559	30
	4	.548	.260	30	.611	.321	30	.369	.151	30
Stem Volume (Cm^3)	1	13	16	28	9.2	17	29	15	14	20
	2	1.94	6.48	29	3.40	3.63	30	1.57	1.55	20
	3	.0894	.0795	30	.107	.117	30	.0368	.0308	30
	4	5.3	10.6	30	15.8	18.4	30	1.08	1.62	30
Total Volume (Density x Stem Volume) (Cm^3)	1	814	--	--	1,075	--	--	3,825	--	--
	2	225	--	--	391	--	--	265	--	--
	3	7.4	--	--	12.7	--	--	3.09	--	--
	4	2,390	--	--	4,171	--	--	346	--	--

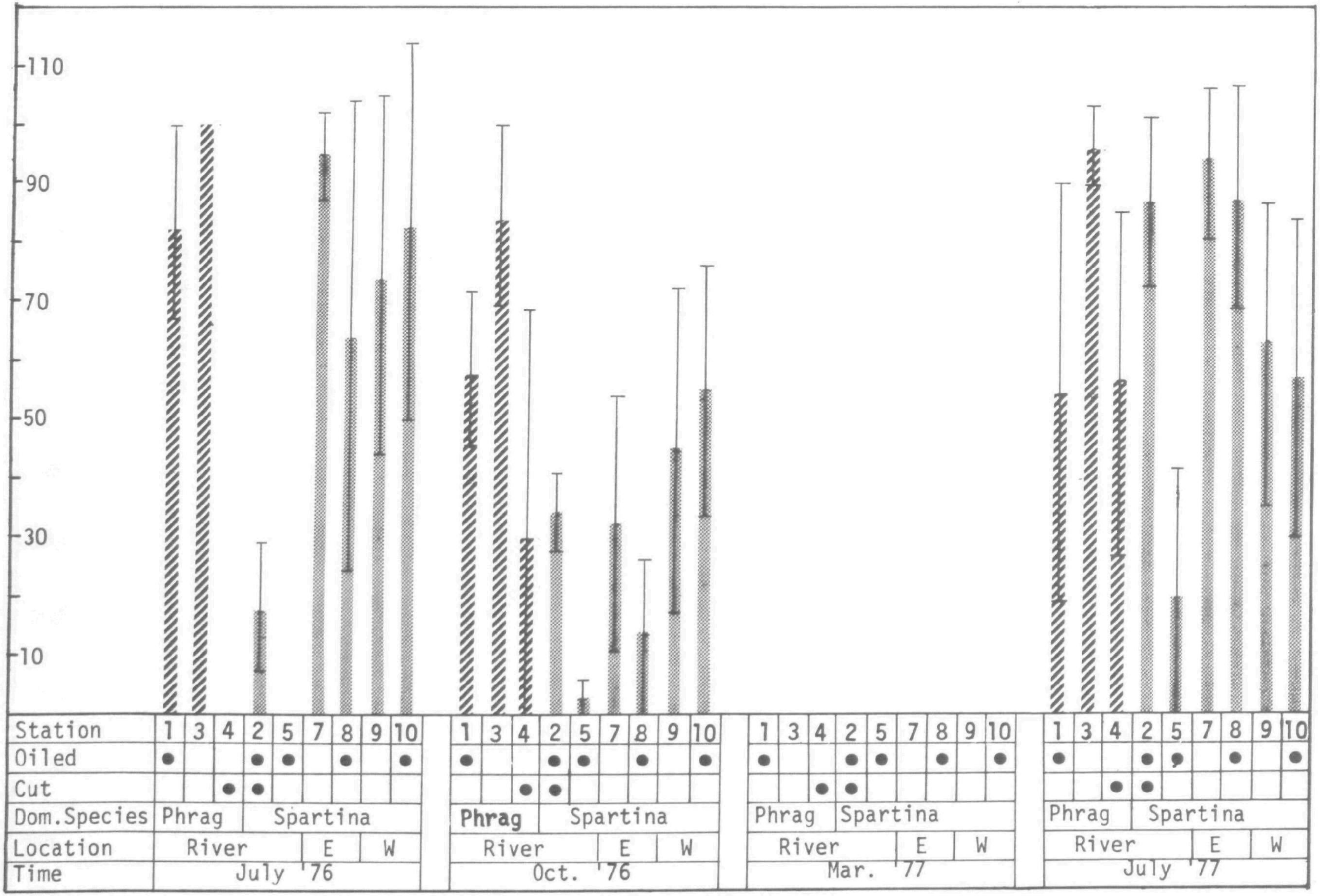

Figure A-1. % Cover

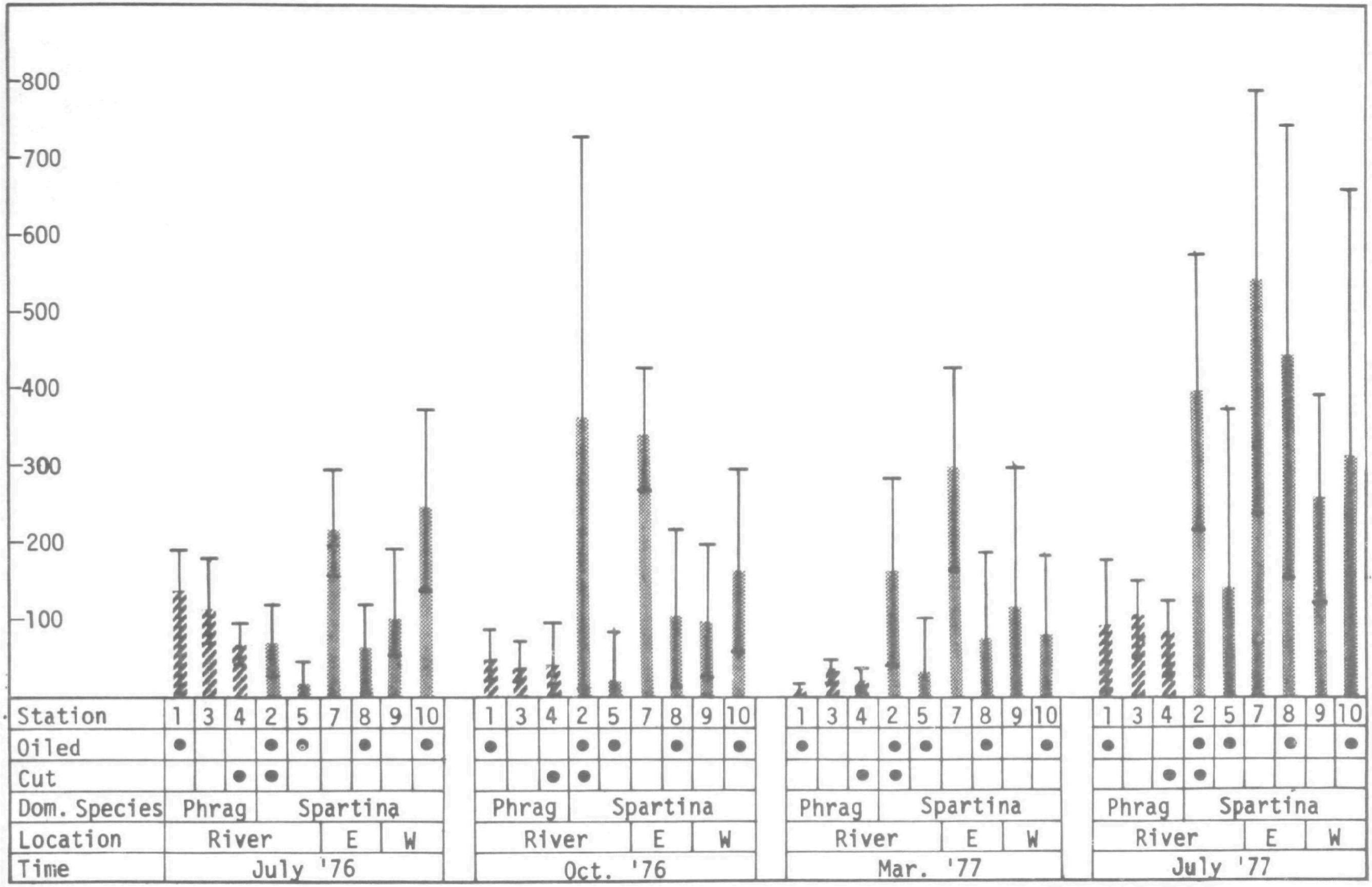

Figure A-2. Density (stems/m^2)

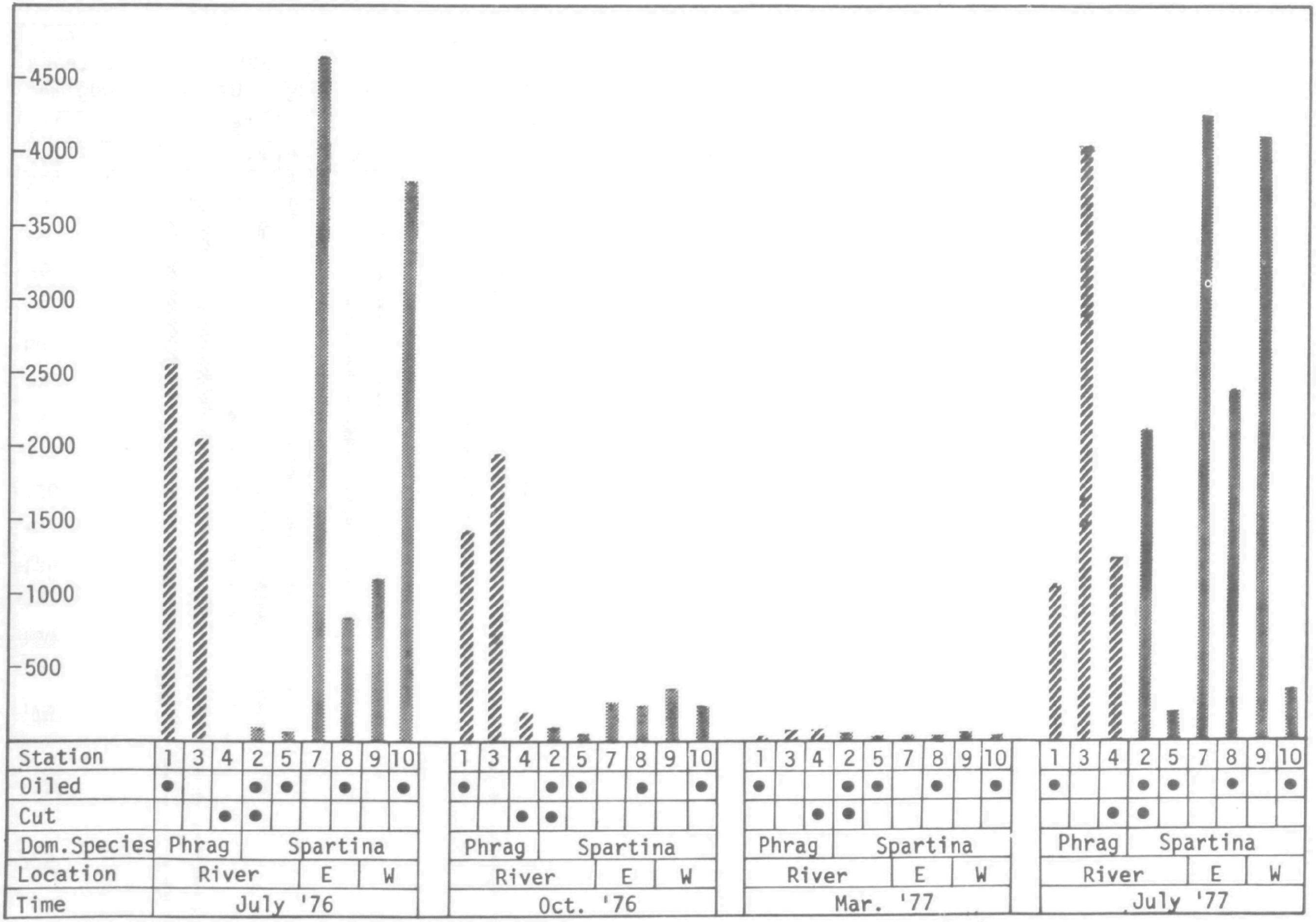

Figure A-3. Total Plant Volume Per Unit Area (cm^3/m^2)

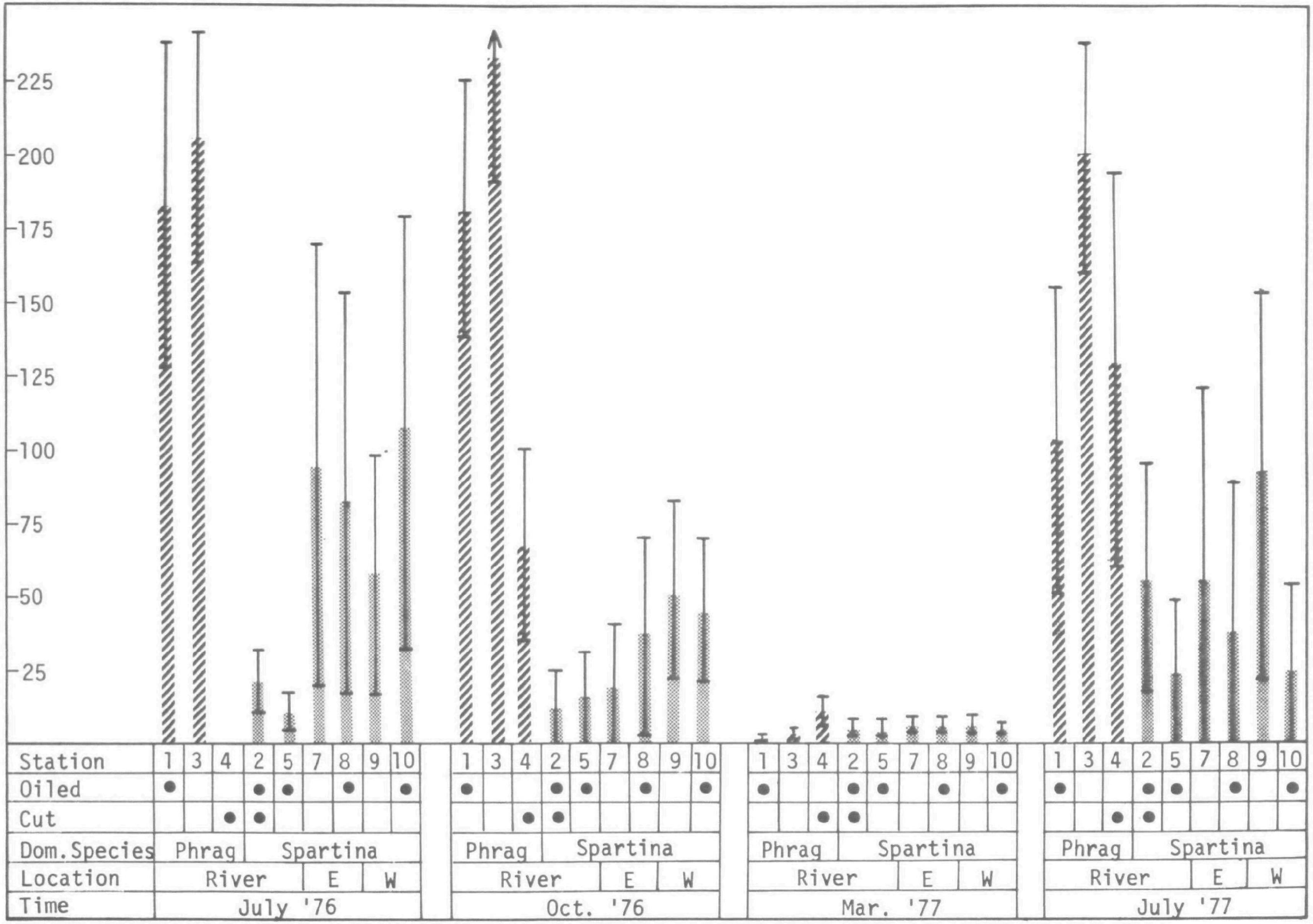

Figure A-4. Height (cm)

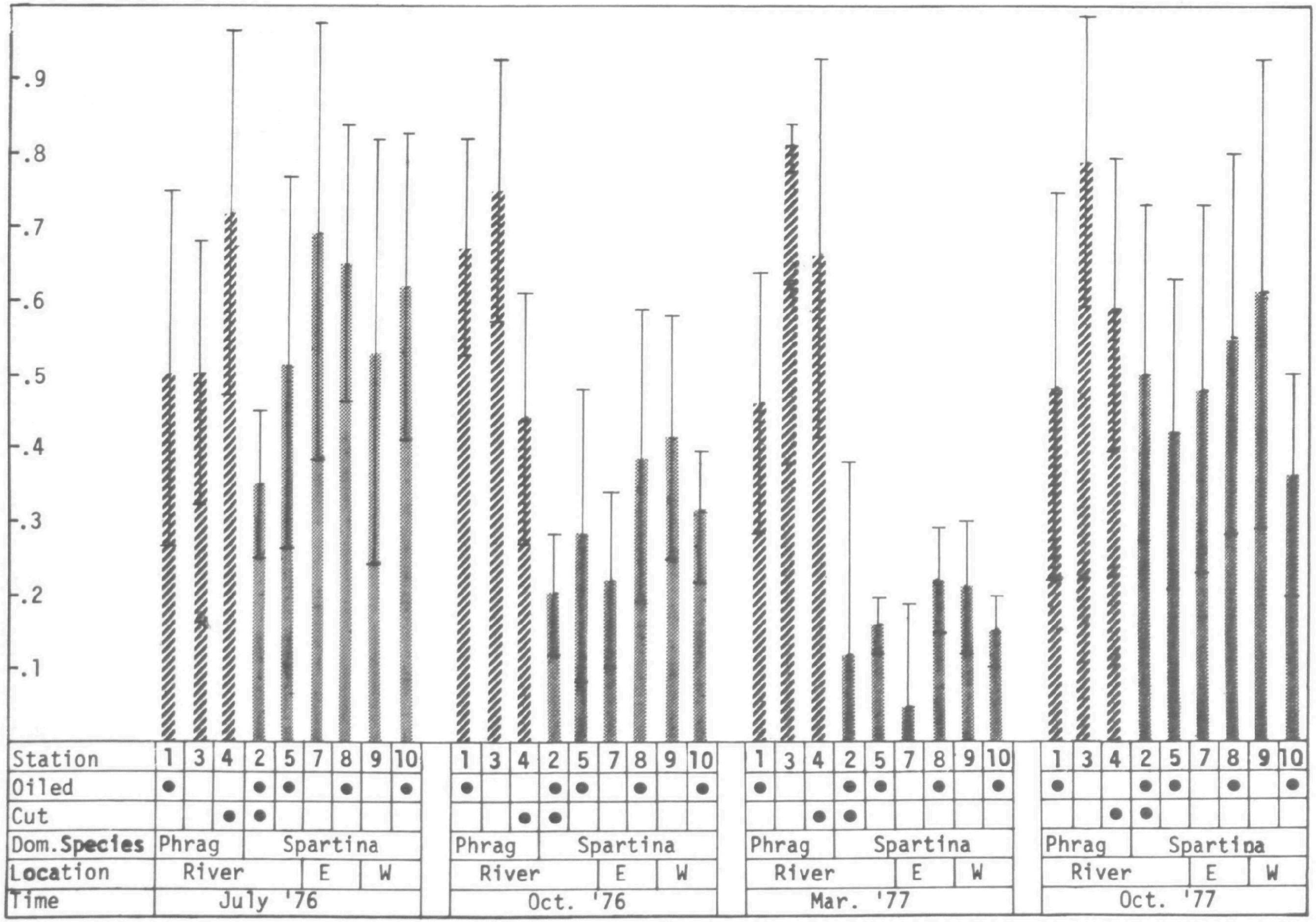

Figure A-5. Diameter (cm)

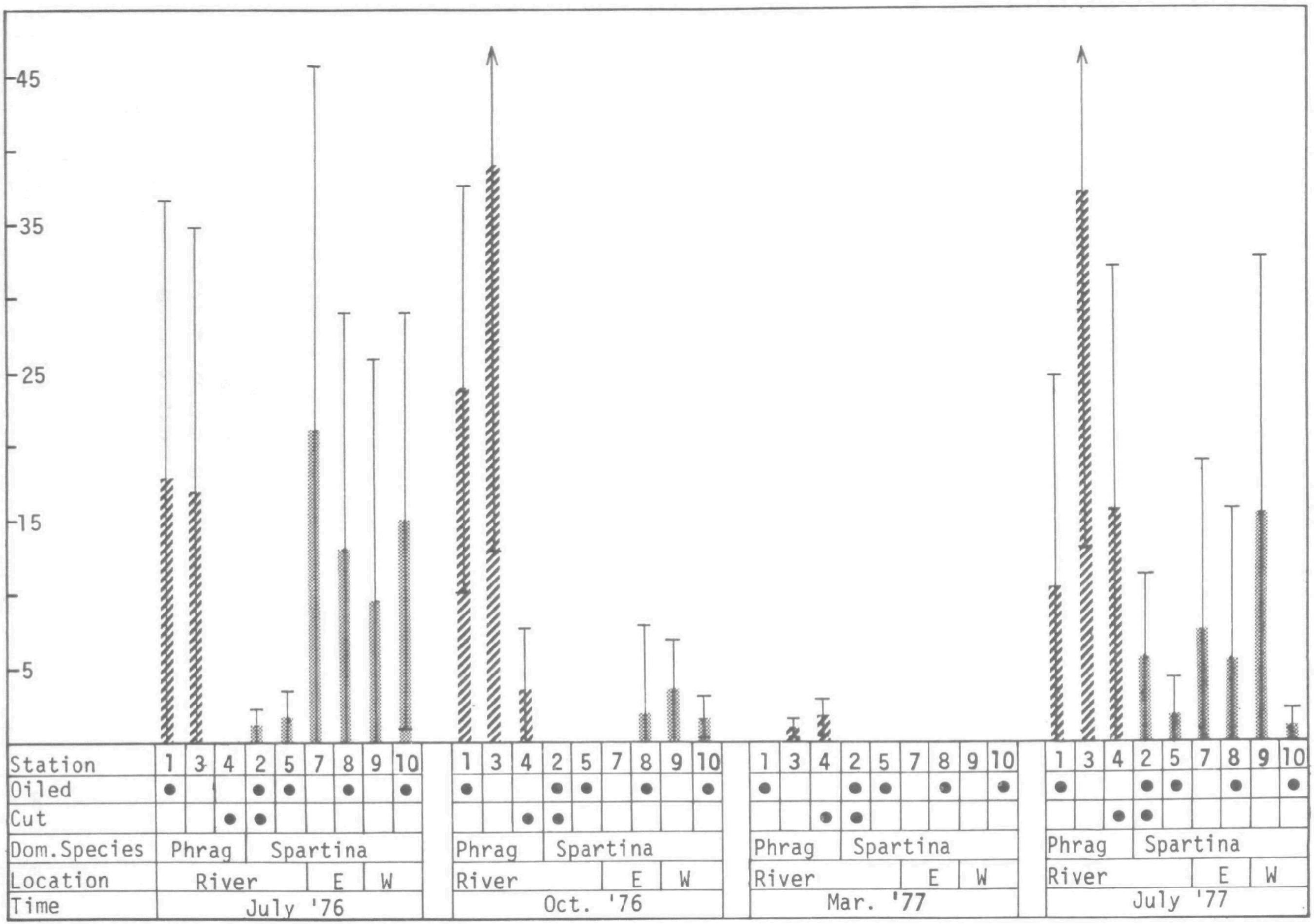

Figure A-6. Individual Stem Volume (cm^3)

Table A-3

MARSH SOIL INVERTEBRATE POPULATIONS

		Station 1	Station 2	Station 3	Station 4	Station 6	Station 7	Station 8	Station 11	Tide
	Habitat:	Phragmites	Spartina marsh	Phragmites	Phragmites	Mudflat	Spartina Marsh	Spartina Marsh	Mudflat	
	Sediment:	Firm	Firm	Firm	Firm	Soft	Soft	Soft	Soft	
	Flushing:* Overflow	Low	Low	Low	Low	Low	Low	Moderate	Low	
	Throughput	High	High	High	High	Low	Low	Low	Low	
	Location:	River	River	River	River	E	E	E	W	
	Treatment:	Oiled	Oiled & Cut	None	Cut	Oiled	None	Oiled	Oiled	
July '76	Polychaetes	64	6	0	2	0			809	
	Oligochaetes	258	533	22	36	0			29	
	Molluscs	0	0	0	1	0			1	
	Crustaceans	3	1	5	28	0			0	1,2,3,4:Low 6,11:High
	Insects	0	0	1	0	0			54	
Oct. '76	Polychaetes	0	0	0	0		0	227		
	Oligochaetes	65	3	1	0		31	448		
	Molluscs	0	0	0	0		0	0		Low
	Crustaceans	6	1	2	8		32	19		
	Insects	0	0	1	0		1	1		
Mar. '77	Polychaetes	4	0	0	0		3	0		
	Oligochaetes	38	75	0	17		41	61		
	Molluscs	0	0	0	0		0	0		Low
	Crustaceans	0	0	0	4		3	2		
	Insects	0	0	0	0		0	0		
Jul. '77	Polychaetes	0	0	0	4		9	49		
	Oligochaetes	72	90	0	87		118	6		
	Molluscs	1	0	0	0		47	1		Low
	Crustaceans	0	0	0	1		10	2		
	Insects	0	0	0	0		0	0		

*Overflow = degree to which the plants themselves are flushed by tidal flows
Throughput = rate at which surrounding waters are removed from the marsh system.

Table A-4

MARSH SOIL FAUNA: NUMBER OF INVERTEBRATE GENERA AND INDIVIDUALS, AND INVERTEBRATE DIVERSITY INDEX

		Station 1	Station 2	Station 3	Station 4	Station 6	Station 7	Station 8	Station 11	Tide
	Habitat:	Phragmites	Spartina marsh	Phragmites	Phragmites	Mudflat	Spartina Marsh	Spartina Marsh	Mudflat	
	Sediment:	Firm	Firm	Firm	Firm	Soft	Soft	Soft	Soft	
	Flushing:* Overflow	Low	Low	Low	Low	Low	Low	Moderate	Low	
	Throughput	High	High	High	High	Low	Low	Low	Low	
	Location:	River	River	River	River	E	E	E	W	
	Treatment:	Oiled	Oiled & Cut	None	Cut	Oiled	None	Oiled	Oiled	
July '76	Genera	8	11	7	7	0	0		6	
	Individuals	344	542	28	67	0			893	
	Diversity Index**	1.346	.584	1.188	1.211	Undefined			.443	1,2,3,4:Low 6,11:High
Oct. '76	Genera	5	3	4	2		6	9		
	Individuals	71	4	4	8		67	692		Low
	Diversity Index**	1.362	1.040	1.386	.562		1.345	1.197		
Mar. '77	Genera	4	3	0	5		6	4		
	Individuals	42	75	0	21		47	63		Low
	Diversity Index**	.800	.555	Undefined	1.273		.838	.823		
Jul. '77	Genera	4	2	0	4		7	5		
	Individuals	73	100	0	92		184	58		Low
	Diversity Index**	.723	.325	Undefined	.503		1.219	.802		

*Overflow = degree to which the plants themselves are flushed by tidal flows.
Throughtput = rate at which surrounding waters are removed from the marsh system.
**Shannon-Weaver

Table A-5

Observed Changes in Soil Surface Elevation at Sedimentation Stakes (cm)

		INTERIOR MARKER				OUTER MARKER			
Station	Description	July 1976 to October 1976	October 1976 to March 1977	March 1977 to July 1977	Net Change	July 1976 to October 1976	October 1976 to March 1977	March 1977 to July 1977	Net Change
1	Uncut oiled river	+ 1.3	-1.3	0.0	0.0	- 2.5	- 0.6	-0.7	-3.8
2	Cut oiled river	- 1.2	+0.6	--	--	--	--	--	--
3	Uncut unoiled tributary	- 3.2	-1.3	0.0	-4.5	- 1.8	-15.9	--	--
4	Cut unoiled tributary	+ 0.6	-2.5	+0.6	-1.9	+ 1.3	+ 1.9	0.0	-0.6
5	Uncut oiled river bend	- 0.6	0.0	0.0	-0.6	+ 0.3	- 2.2	0.0	-1.9
7	Uncut unoiled interior marsh	+ 1.3	-0.6	0.0	+0.7	+ 2.5	- 1.9	1.9	+2.5
8	Uncut oiled interior marsh	+ 2.5	--	--	--	+ 3.1	+ 3.8	-0.6	+6.3
9	Uncut unoiled interior marsh	+12.1	--	--	--	-22.5	--	--	--
10	Uncut oiled interior marsh	+ 2.6	-1.3	+1.3	+2.6	+ 7.6	--	--	--

Table A-6

Observed Changes in Position of Shoreline Break-in-Slope (cm)

Station	Description	July 1976 to October 1976	October 1976 to March 1977	March 1977 to July 1977	Net Change
1	Uncut oiled river	- 3.8	-1.9	+ 3.9	- 1.8
2	Cut oiled river	-115.6	+1.3	--	-209.6
3	Uncut unoiled tributary	- 7.6	-4.5	-17.1	- 29.2
4	Cut unoiled tributary	- 3.2	-3.8	+ 8.9	+ 1.9
5	Uncut oiled river bend	+ 1.3	+2.6	+ 1.2	+ 5.1

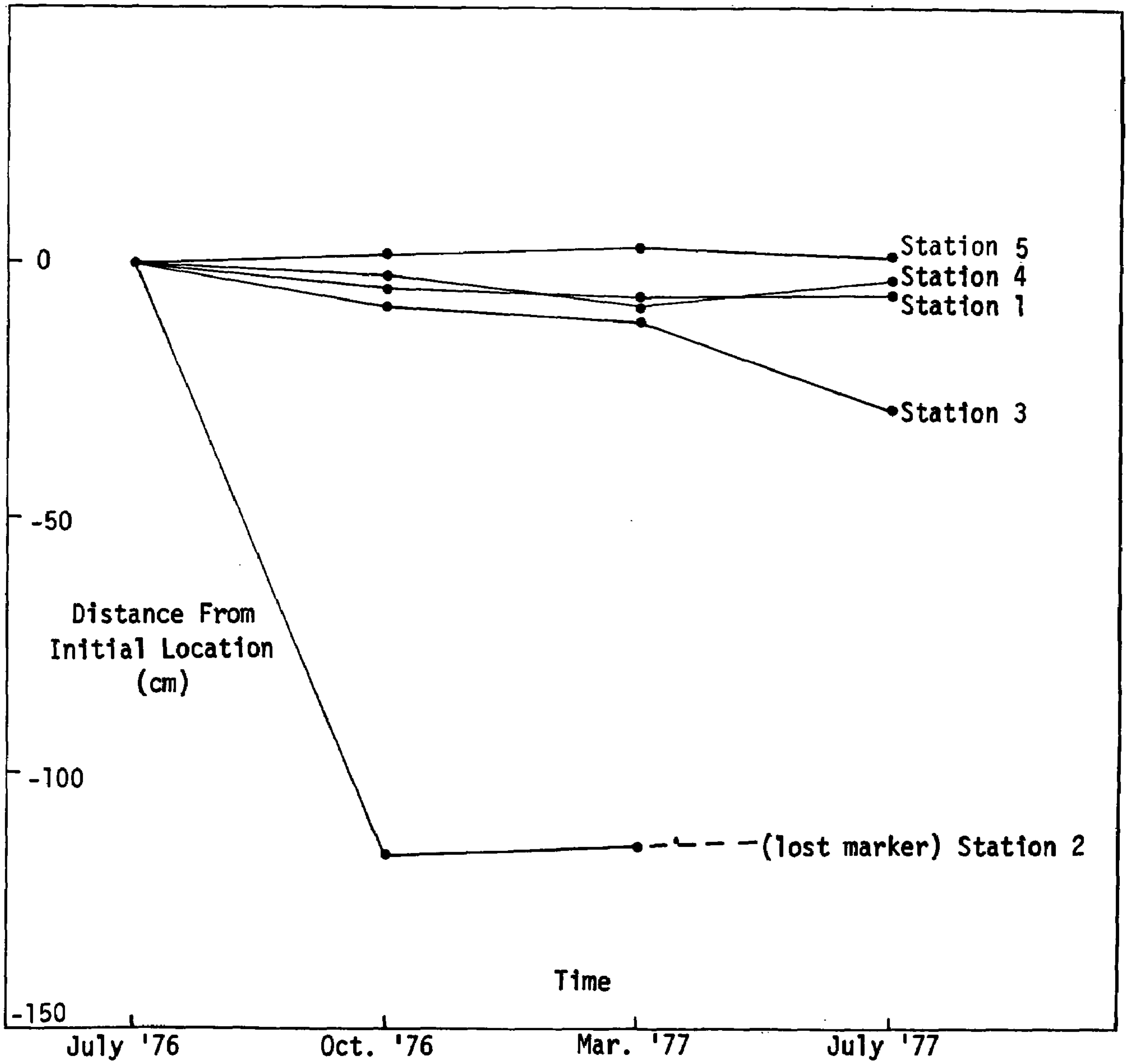

Figure A-7. Position of Bank Edge vs. Time

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

1. REPORT NO. EPA-600/7-78-109	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE RESPONSE OF A SALT MARSH TO OIL SPILL AND CLEANUP: Biotic and Erosional Effects in the Hackensack Meadowlands, New Jersey		5. REPORT DATE June 1978 issuing date
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Phillip C. Dibner		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS URS COMPANY, 155 Bovet Road, San Mateo, California 94402		10. PROGRAM ELEMENT NO. EHE 623
		11. CONTRACT/~~GRANT~~ NO. 68-03-2160
12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Laboratory-Cin. OH, Office of Research and Development, U.S. Environmental Protection Agency, Cincinatti, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final 5/76 - 12/77
		14. SPONSORING AGENCY CODE EPA/600/12
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

This study addresses the biological and erosional response of portions of the Hackensack Meadowlands estuarine marsh to the Wellen Oil Company number 6 crude oil spill of late May 1976, and the subsequent cleanup operations. Cleanup included cutting and removal of oiled grasses of the species Spartina alterniflora from the bank of the Hackensack River. Data were gathered from several locations along the river bank and in the inner marsh during four sampling sessions, at approximately 4 month intervals, throughout the year following the spill. The productivity of the marsh plants, the composition of marsh soil invertebrate communities, the presence of oil in the substrate, and erosional trends were monitored. Results suggest that cutting heavily oiled Spartina soon after contamination saved the plants from dying by root suffocation. However, the foot traffic associated with cutting is implicated as having made the river bank susceptible to severe erosion by boat wakes and other sources of erosive energy. It is concluded that cutting is only desirable in a limited range of circumstances, determined by the characteristics of the contaminating oil, the biology of affected plants, and the time of year.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Substrates Swamps Invertebrates Grasses Erosion	Cleanup Hackensack Meadowlands New Jersey Oil Spill Pragmites communis Spartina alterniflora Salt Marsh	43F 68D 91A

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