1991

Analysis of vegetation patterns in a tidal freshwater marsh

James E. Perry III
College of William and Mary - Virginia Institute of Marine Science

Order Number 9122957

Analysis of vegetation patterns in a tidal freshwater marsh

Perry, James Ernest, III, Ph.D.

The College of William and Mary, 1991

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

ANALYSIS OF VEGETATION PATTERNS IN A TIDAL FRESHWATER MARSH

A Dissertation

Presented to

The Faculty of the School of Marine Science

The College of William and Mary in Virginia

In Partial Fulfillment

Of the Requirements for the Degree of

Doctor of Philosophy

---

by

James E. Perry, III

1991

APPROVAL SHEET

This dissertation is submitted in partial fulfillment of the

requirements for the degree of

Doctor of Philosophy

James E. Perry, III

Approved, January, 1991

Carl H. Hershner, Ph.D. (Co-chairman)

Gene M. Silberhorn, Ph.D. (Co-chairman)

Thomas Barnard, MS

David Evans, Ph.D.

Richard Wetzel, Ph.D.

Carvel Blair, Ph.D. (outside member)
Institute of Oceanography
Old Dominion University
(Emeritus)

DEDICATION

To Rhea and Sue...
...thanks for the memories.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

I wish to thank Drs. Carl Hershner and Gene Silberhorn, my committee co-chairmen, for their guidance and support throughout this study. I gratefully acknowledge the helpful criticisms, comments and suggestions from committee members Mr. Tom Barnard, Drs. Carvel Blair, David Evans, and Dick Wetzel.

A special thanks goes to Dr. John Boon and Bob Lukens for providing the computer programs and mathematical models necessary to calculate the tidal parameters needed in this study. Special thanks also is given to Mr. C. "Woody" Hobbs for his critical input on the manuscript and, above all, his moral support.

Thanks also to all the good folks who helped collect the field data under what was not always the best of conditions: Robert Atkinson, Conrad Austin, Tom Barnard, Julie Bradshaw, James Catallo, Carroll Curtis, Kirk Havens, Willy Reay, Chuck Roadley, Maryanne Wohlgemuth and to the many, many others whose names I presently cannot remember.

Much appreciation is extended to Sharon Dewing and Berch Smithson for their help in digitizing and analyzing map information and preparing many of the maps used in the following manuscript.

Encouragement was received from Walter Priest, Lyle Varnell, Dr. Norlyn Bodkin, and the members of the Mid-Atlantic Paddlers Association (Charlie B., Joe, Dave, Charlie S., Jim, and others).

Thanks to Dr. Hilary Neckles and Ken Moore for their help with computer programming and software packages (and to Hilary for keeping the desk elves busy!). Judy Hudgins helped with parts of the manuscript (sorry I had to change it so many times, Judy).

Thanks to the VIMS Vessel Operation crew (Sharon, George, Robert, Ricky, Shirley, and Jim) for keeping me afloat on rough seas, to the VIMS Library staff (Susan, Marilyn, and Diane) for their help with retrieving the necessary literature, to the VIMS Computer Center (Pat, Gary, Bob, David, Kevin, and Grady) staff for keeping me in (on?) line, and to the NOAA Atlantic Marine Center (Jim Dixon) for the use of a tide guage throughout this study.

Finally, thanks to my family for the patience, understanding, and moral support that they provided through some very trying times.

LIST OF TABLES

LIST OF FIGURES

ANALYSIS OF VEGETATION PATTERNS IN A TIDAL FRESHWATER MARSH

ABSTRACT

Tidal freshwater wetlands represent a transitional wetland between tidal salt marshes and non-tidal wetlands. As such, they exhibit some of the vegetation characteristics of both systems. If the changes in the vegetation pattern favor the characteristics of of one system over the other, the changes may be an indication of changes in the environmental conditions of the estuarine ecosystem that favors that system. Unfortunately, little is known of the temporal and spatial changes that occur in the vegetation patterns of tidal freshwater marshes of the mid-Atlantic coastal region.

In 1987 a vegetation analysis was done on a 60 hectare section of Sweet Hall Marsh, a tidal freshwater marsh of Chesapeake Bay. The data was compared with that of a similar study completed in 1974 to determine the changes that may have occurred in the vegetation pattern of the marsh. The results found that there was no significant difference in the species diversity of the two studies. However, further analysis showed that there was a change in the plant species contributing to the diversity. Spartina cynosuroides, an oligohaline species that was not important in the 1974 study, had the fourth highest importance value in this study. The shift in species composition of Sweet Hall Marsh may reflect a shift in the marsh's environment from being historically that of tidal fresh water to one of being more transitional between oligohaline and tidal fresh water.

James E. Perry, III

SCHOOL OF MARINE SCIENCE

THE COLLEGE OF WILLIAM AND MARY IN VIRGINIA

ANALYSIS OF VEGETATION PATTERNS IN A TIDAL FRESHWATER MARSH

INTRODUCTION

Wetlands are no longer considered an expendable part of our natural resources. They are valued for the functional roles they play in providing wildlife nesting, breeding, and foraging habitat, in water quality and flood control processes, and as shoreline erosion buffers. It is now accepted that a diverse array of wetland types provide a high number of habitats and, therefore, increase the number and types of roles played by wetlands within the watershed.

For the most part, the functional values of a wetland are tied directly to the types, numbers, and distribution of plant species within that wetland, i.e. the vegetation pattern of that wetland. For example, the foraging, nesting, and breeding potential of a forested wetland differs from that of a saltmarsh due to the different types of plants found in each. Similarly, the ability of a saltmarsh to buffer erosion differs from that of a tidal freshwater marsh due to the difference in herbaceous habit and seasonal plant communities of the two (Odum et al.,1984, Odum, 1988).

The vegetation pattern of a wetland depends upon the environmental and biological parameters of a system. Important environmental parameters include inundation periodicity (tides, flooding, etc.), water chemistry (presence of salts, nutrients, etc.), edaphic conditions, and climate (length of growing season, precipitation, ambient temperatures, etc.). Biological parameters include plant propagule availability, life history and competitive ability as well as grazing and parasite pressure. Variation in either type of parameter may bring about changes in vegetation assemblages. These changes can occur over varying time scales from days (e.g. as a result of stochastic events) to months (e.g. in response to grazing) to years (e.g. from propagule availability or sea level rise). It would be beneficial to scientists and managers alike to be able to better define and understand these changes in wetlands vegetation over time. This information would be a valuable tool for assessing the functional role wetlands play in estuarine ecosystems and for evaluating the impacts of natural and human-induced impacts on these systems.

In Sweet Hall Marsh, a tidal freshwater marsh located on the Pamunkey River, King William County, Virginia and the site used for this study, changes in the vegetation pattern have been noticed by members of the local hunt club who are frequent users of the marsh (Tacoma Hunting and Fishing Club, personal communication). Over the past several decades they noticed a shift in the dominance of the vegetation towards "tall grass like species" (which they presumed had lower waterfowl value). Inquires into a scientific reason for the change revealed some historical quantitative data of the spatial vegetation patterns in Sweet Hall Marsh, but not enough to document these changes. Furthermore, since monitoring changes in vegetation patterns has only recently become of interest to politicians and managers, few methods were available in the literature for determining temporal changes in vegetation patterns at a scale or resolution necessary for Sweet Hall Marsh. Therefore, a new set of methods needed to be established to depict spatial arrays of vegetation assemblages using aerial photographs, as well as to make descriptive and statistical comparisons with data from a previous vegetation study done on Sweet Hall Marsh (Doumlele, 1976).

Changes in Wetland Vegetation Patterns and Sea Level Rise

Sweet Hall Marsh represents a transitional wetland along salinity and tidal gradients from the upstream non-tidal fresh to downstream tidal saltwater wetland habitats. Therefore, it is an excellent area to investigate changes that may occur in vegetation patterns as a result of changes in time of inundation and salinity stress which may be brought about by changes in relative sea level.

Between the years 1956 and 1977, the Commonwealth of Virginia lost an estimated 63,000 acres (25,500 hectares) of its coastal wetlands. Although most of the loss was due to urban development, the relative rise in sea level played a significant role, particularly in the Chesapeake Bay (EPA, 1987).

The consequences of sea level rise occur in the physical, geological, and chemical regimes of the Bay's estuaries. Of particular importance is an increase in the local mean water level and intrusion of the tide and salinity farther upstream. Changing inundation periodicity and salinity can be expected to impact wetland vegetated patterns.

Inundation periodicity is affected by sedimentation processes of the system. Where sediment accretion rates keep pace with the rate of sea level rise, the inundation periodicity of the wetland is relatively unchanged. However, where sediment accretion rates do not keep pace with the rate of sea level rise, inundation periodicity is increased. In the latter situation there is a shift in the components of a vegetation pattern toward plant species that are more hydrophytic in nature. Unabated, the trend leads to total inundation of a wetland and conversion to sub-aqueous habitat.

Increasing water salinity results in increased soil salinity in intertidal systems. When this occurs, a wetland's vegetation pattern responds with a shift toward plant species that are more halophytic in nature (ref. V.J. Chapman, 1960; Mitsch and Gosselink, 1985).

The extent to which these processes are occurring in Chesapeake Bay is yet unknown. One approach to developing a better understanding of these processes is to reconstruct a chronology of the spatial and temporal changes in wetland patterns of a wetland system and to correlate them with changes in the physical, geological, and chemical parameters of the system.

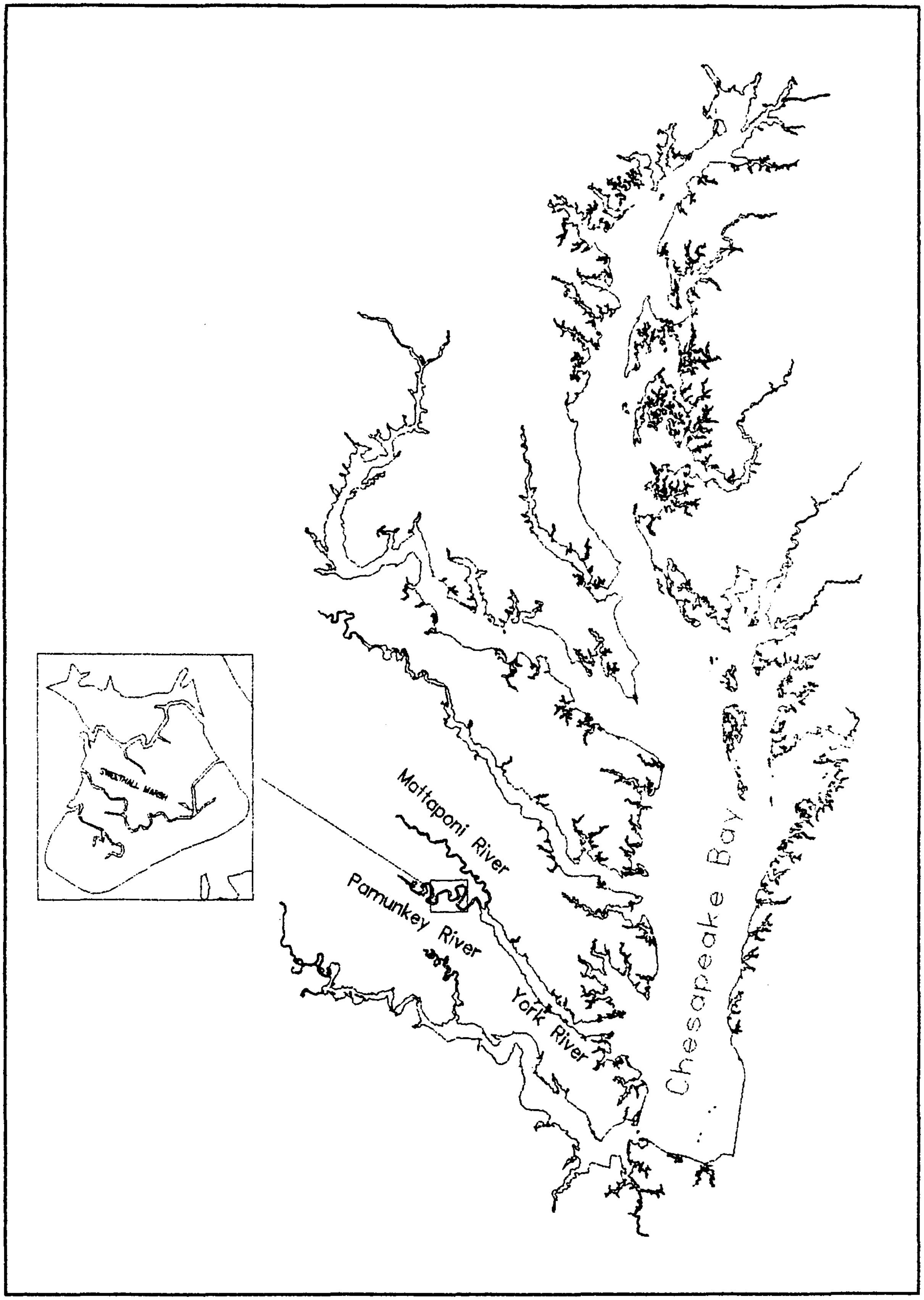
The primary purpose of this study is to determine the historic spatial and temporal changes in the vegetation pattern of a 60 hectare portion of Sweet Hall Marsh.

As well, an attempt was made toward the second step in the process, that is to describe the trends of certain physical, geological, and chemical parameters of the estuary adjacent to Sweet Hall Marsh and their possible relationship to changes in the marsh's vegetation pattern, particularly inundation periodicity and salinity. However, since the primary objective of the study was to determine vegetation changes, a time intensive process, only a cursory overview of the environmental parameters was possible. These trends were used to develop a conceptual model of vegetation changes of Sweet Hall Marsh.

Physical Setting

The Pamunkey River flows in a northwest to southeast direction. It combines with the Mattaponi River at the town of West Point to form the York River, one of the main tributaries of Chesapeake Bay (Figure I1). The river basin is approximately 133km (83 miles) long as the crow flies, but, because of its meandering, it contains 220 km (137 miles) of river channel. The tidal portion of the river extends upstream 90km (56 miles) from the mouth (Brooks, 1983). Found between meanders are numerous point marshes and forested wetlands, some of which are over 405 hectares (1000 acres) in size. The arrangement of wetlands in the river basin represents a continuum of marsh types along a salinity and tide gradient with the tidal oligohaline marshes found at the mouth and non-tidal freshwater marshes and swamps in the headwaters of the Pamunkey.

Figure 1. Location map of Sweet Hall Marsh and the Pamunkey River. The Pamunkey River is part of the headwater system of the York River, one of the main tributaries of Chesapeake Bay.


SWEETHALL MARSH
Mattaponi River
Pamunkey River
York River
Chesapeake Bay

The climate of the area is humid, subtropical (Brooks, 1983) and has a growing season of 175 days (based on consecutive days >32^{o}F for 9 years in 10; National Cooperative Soil Survey, 1980). The annual average temperature of the river basin is 56.3^{o}F (13.5^{o}C) with the annual highs coming in August (25.7^{o}C (78.3^{o}F)) and lows in February (0.9^{o}C (33.6^{o}F)). The water temperature of the river basin shows seasonal trends that follow the ambient air temperatures with a one to two week lag time. Highs come in August (approx. 27.5^{o}C (81.5^{o}F)) and lows in February (approx. 5.5^{o}C (41.9)). Precipitation in the area is 95.9cm (45 inches) and is highest in July and August and lowest between September and January (Brooks, 1983).

Freshwater discharge into the headwaters of the Pamunkey River is measured at Hanover, Va., approx. 115km (72 miles) upstream from the study site. Over 39 years the discharge ranged from 0.34m^3 sec^{-1} to 1,140m^3 sec^{-1} (12$ft^3sec^{-1}$to 4.03 x $10^4ft^3sec^{-1}$). Mean daily average discharge is 28.74m^3 sec^{-1} (1 x $10^3ft^3sec^{-1}$)(Brooks, 1983). Since the river has a mean low water volume of 1.098 x 10^8m^3 (3.88 x 10^9ft^3)(Brooks, 1983), the residence time of the freshwater entering the system, ignoring tidal effects, is approximately 104 days.

The shoreline upstream of the study site consist of 116.9km (72.6 miles) of fastlands (upland-wetland or upland-estuary interfaces). This includes 4.5km (2.8 miles) of high shores with steep bluffs, usually indicative of high energy upland-estuary interfaces, and 146.1km

(90.7 miles) of low shore (marsh-estuary interface). South of the site are 55.6km (34.5 miles) of marsh shore and 48.1km (29.9 miles) of fastland shore, including 3.7km (2.3 miles) of steep bluffs (Hobbs et al., 1975).

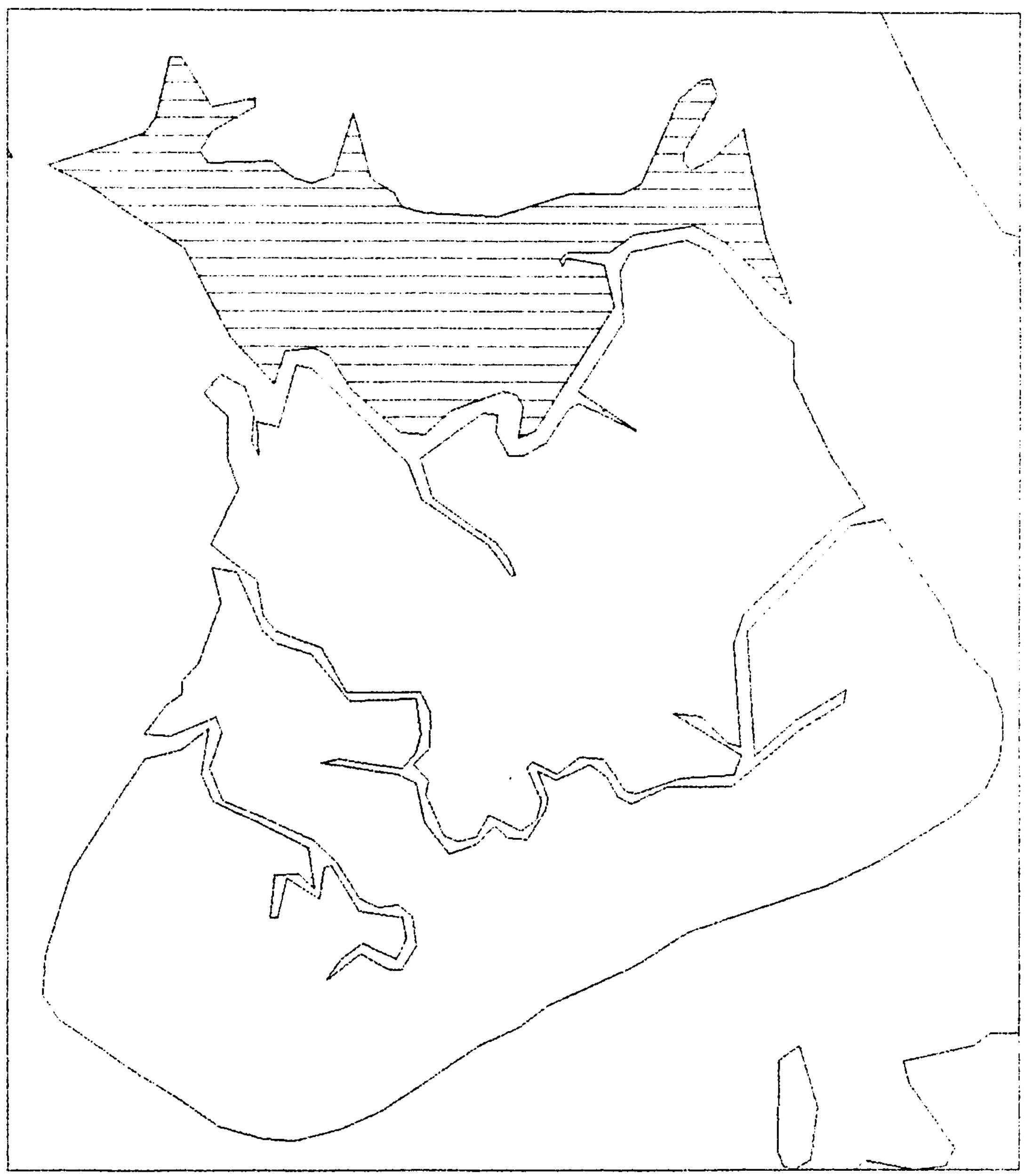
Site Description

The site chosen for this study is a 60 hectare (148 acre) tidal freshwater marsh portion of Sweet Hall Marsh (Figure I2). Tidal freshwater marshes are wetlands that are dominated by a freshwater biota, are subjected to lunar (astronomical) tides, and receive enough freshwater flow to maintain a average annual salinity of 0.5 parts per thousands (ppt.) or less (Simpson et al., 1983; Odum et al., 1984; Mitsch and Gosselink, 1986). Located on the Pamunkey River in eastern Virginia, it is the fourth point marsh encountered when traveling upstream approximately 20km (12.4 miles). The entire Sweet Hall Marsh system contains approximately 444 hectares (1100 acres) of wetlands including 29 hectares (72 acre) of forested wetlands, 30 hectares (74.1 acres) of open water and tidal streams, and 385 hectares (951 acres) of mixed broadleaved-graminoid herbaceous wetlands (Doumlele, 1976). It is classified as a palustrine emergent, regularly flooded habitat in the classification scheme of Cowardin et al. (1979). Land use of the uplands adjacent to the marsh includes silviculture and agriculture (Hobbs et al., 1975).

Figure 2. Location of study site. The site consisted of a 60 hectare (150 acres) portion of Sweet Hall Marsh.

SWEETHALL MARSH

STUDY AREA



The mean tide range at the site is 0.83m (2.7 ft) (Brooks, 1983; U.S. Dept. Comm., 1987). The estuary adjacent to the marsh is ebb dominated with 6.7 hrs. of flood and 5.7 of ebb. The lag time of the tide in relation to those of the mouth of the Chesapeake Bay (Hampton Roads) is approximately 4 hrs. (U.S. Dept. Comm., 1987). Standing wave tides do not appear to be significant in the system. Average salinity of the site is approximately 0.45 ppt. and ranges from 0 to 7 ppt. (calculated from Brooks, 1983).

Basin topography near the site is typical of marine estuaries with deep channels and adjacent shallow shelves. Channel depths range from 4.5m to 12m (15ft to 40ft) at mean low water and the shelves from 1m to 3m (3ft to 10ft) with some exposed at the time of extreme low water.

Man's activities appear not to have had a significant impact on the system. Presently, only muskrat trapping and wetland research occur within the vegetative portion of the marsh. The adjacent waters and intertidal creeks are used for duck hunting, recreational boating and fishing, and, on a small scale, commercial fishing and eeling. A 4.5m (15ft) long dam constructed on an interior tidal creek has been breached by natural water movements and is no longer functional.

LITERATURE REVIEW

Wetland Classification: General

Geological differences in tidal marshes were noted early in the literature (see Shaler, 1885; Johnson and York, 1915; Johnson, 1925, Knight, 1934, Chapman, 1960; 1974; 1975). Shaler (1885) was one of the earliest to recognized a general difference in marsh types and divided them into three groups:

1. tidal salt marshes with organic soils (salt marshes);
2. alluvial soil, tree and/or shrub dominated freshwater swamps (non-tidal wetlands); and
3. tidal, alluvial, graminoid dominated estuarine swamps (tidal freshwater marshes).

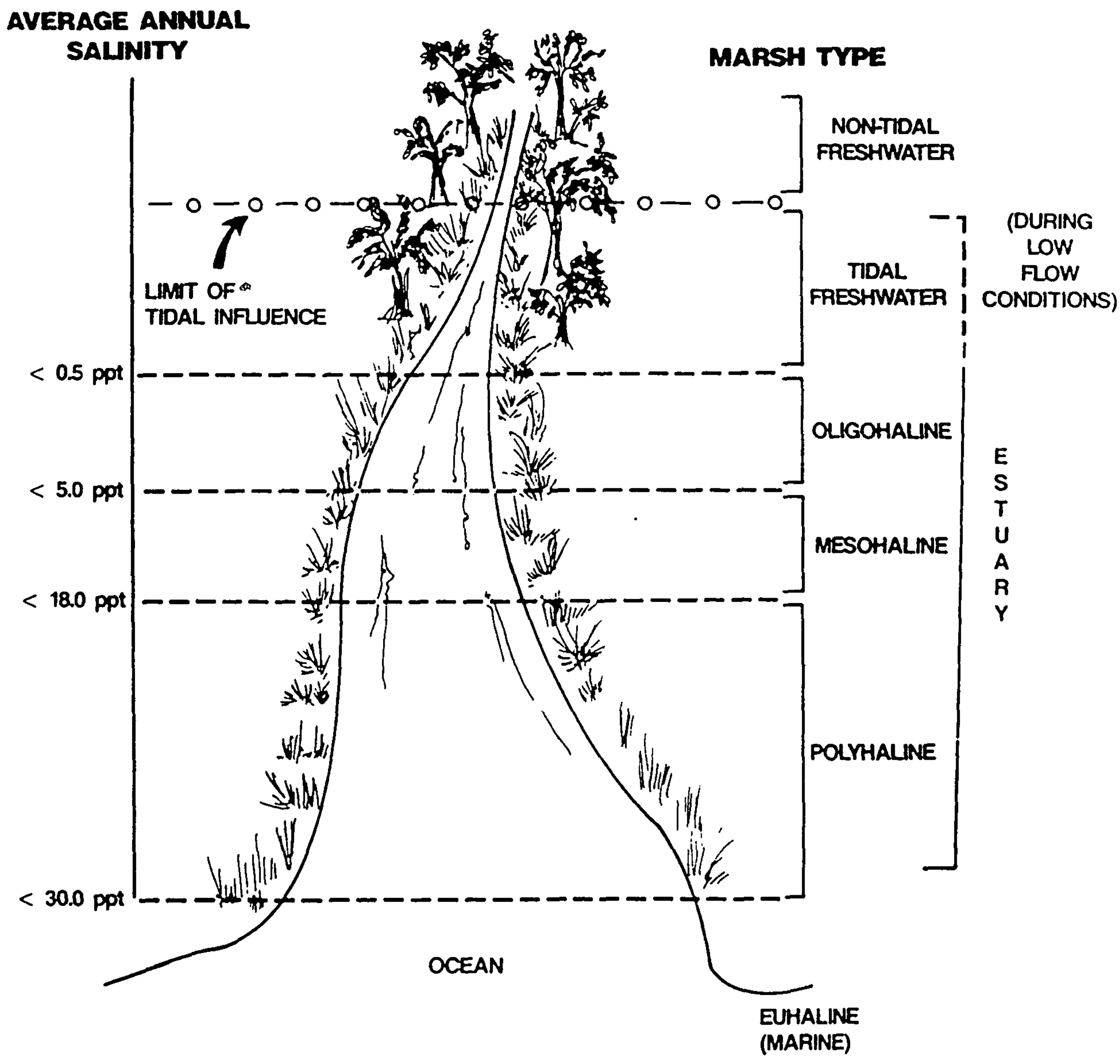
Johnson (1925) divided the tidal salt marshes of the east coast into three geographical types: the Bay of Fundy type, New England type, and the Coastal Plain type. The three types are distinguished by sediments (soft, highly erodable terrestrial bedrock sediment in the Bay of Fundy and Coastal Plain marsh groups, marine sediments on a hard bedrock for the New England group), tidal range (macro-tidal in the Bay of Fundy, macro-and meso-tidal in the New England marshes, mostly micro-tidal in the Coastal Plain), and species composition (Bay of Fundy marshes are *Puccinellia americana* dominated, New England and Coastal Plain are *Spartina* spp. dominated) (Chapman, 1960; 1974; 1975; Frey and Basan, 1976, 1985; Mitsch and Gosselink, 1986). Cowardin et al. (1979)

developed a hierarchical classification scheme that divide wetlands and deepwater habitats into systems, subsystems, classes, and subclasses (dominant life forms). Soil modifiers and flooding regimes are added for each classification.

Wetland Classification: Tidal Freshwater Marshes

Tidal freshwater marshes are wetlands that are dominated by a freshwater biota, are subjected to lunar (astronomical) tides, and receive enough freshwater flow to maintain an average annual salinity of 0.5 parts per thousand (ppt.) (Simpson et al., 1983; Odum et al., 1984; Mitsch and Gosselink, 1986). They represent a transition wetland between the upstream non-tidal fresh and downstream tidal saltwater wetland habitats of bay ecosystem (Figure 1LR) and are the dominant wetland type in the tidal freshwater reaches of the Chesapeake Bay classification scheme (Environmental Protection Agency, 1983). Although no formal attempt has been made to categorize tidal freshwater marshes on the same resolution as the salt marshes, several authors have noted the similarity in the geographic distribution and sediment types of tidal freshwater marshes in reference to Chapman's classification scheme of salt marshes (Odum et al., 1984; Frey and Basan, 1976, 1985; Mitsch and Gosselink, 1986; Odum, 1988). Therefore, it is likely that Chapman's geographical units would hold true for tidal freshwater marshes. Within Cowardin et al.'s (1979) classification, tidal freshwater marshes of

Figure 3. Distribution of tidal wetlands along a salinity gradient. (from Odum et al., 1984)


AVERAGE ANNUAL SALINITY
MARSH TYPE
NON-TIDAL FRESHWATER
LIMIT OF TIDAL INFLUENCE
TIDAL FRESHWATER
(DURING LOW FLOW CONDITIONS)
< 0.5 ppt
OLIGOHALINE
< 5.0 ppt
MESOHALINE
ESTUARY
< 18.0 ppt
POLYHALINE
< 30.0 ppt
OCEAN
EUHALINE (MARINE)

Chesapeake Bay are in the system estuarine, subsystem tidal, class unconsolidated bottom, subclass emergent and have a soil modifying regime of regularly exposed.

Whigham and Simpson (1976) divided tidal freshwater marshes into four major habitats:

1) streams and tidally exposed stream banks that may or may not be vegetated;
2) high marsh areas that are inundated twice daily for 0-4 hrs. by upto 30cm (76.2 inches) of water;
3) pond-like areas that are inundated for approximately 9hrs. during each tide cycle with up to 100cm (254 inches) of water; and
4) pond areas that are continuously inundated but show regular flow reversal coupled with changes in direction.

Simpson et al. (1983) noted that the latter two divisions usually were manifestations of human manipulations (e.g. dredging or placing fill material in tidal freshwater wetlands).

Odum et al. (1984) found Frey and Basan's coastal marsh classification scheme (Frey and Basan, 1976) to be applicable as well to tidal freshwater marshes. A summary of the three classifications, modified from Odum et al. (1984) follows.

Class 1: young marshes only a few hundred years old which are mainly low and intertidal. They are dominated by aquatic and emergent species such as Nuphar luteum (yellow spatter-dock) and Peltandra virginica (arrow-arum).

Class 2: mature marshes consisting of a nearly even mixture of class 1 and class 3 marshes.

Class 3: old marshes that consist mainly of high marshes dominated by high marsh vegetation such as Typha sp. (cat-tails), Hibiscus moscheutos (marsh-mallow), and Iris virginica (blue-flag iris).

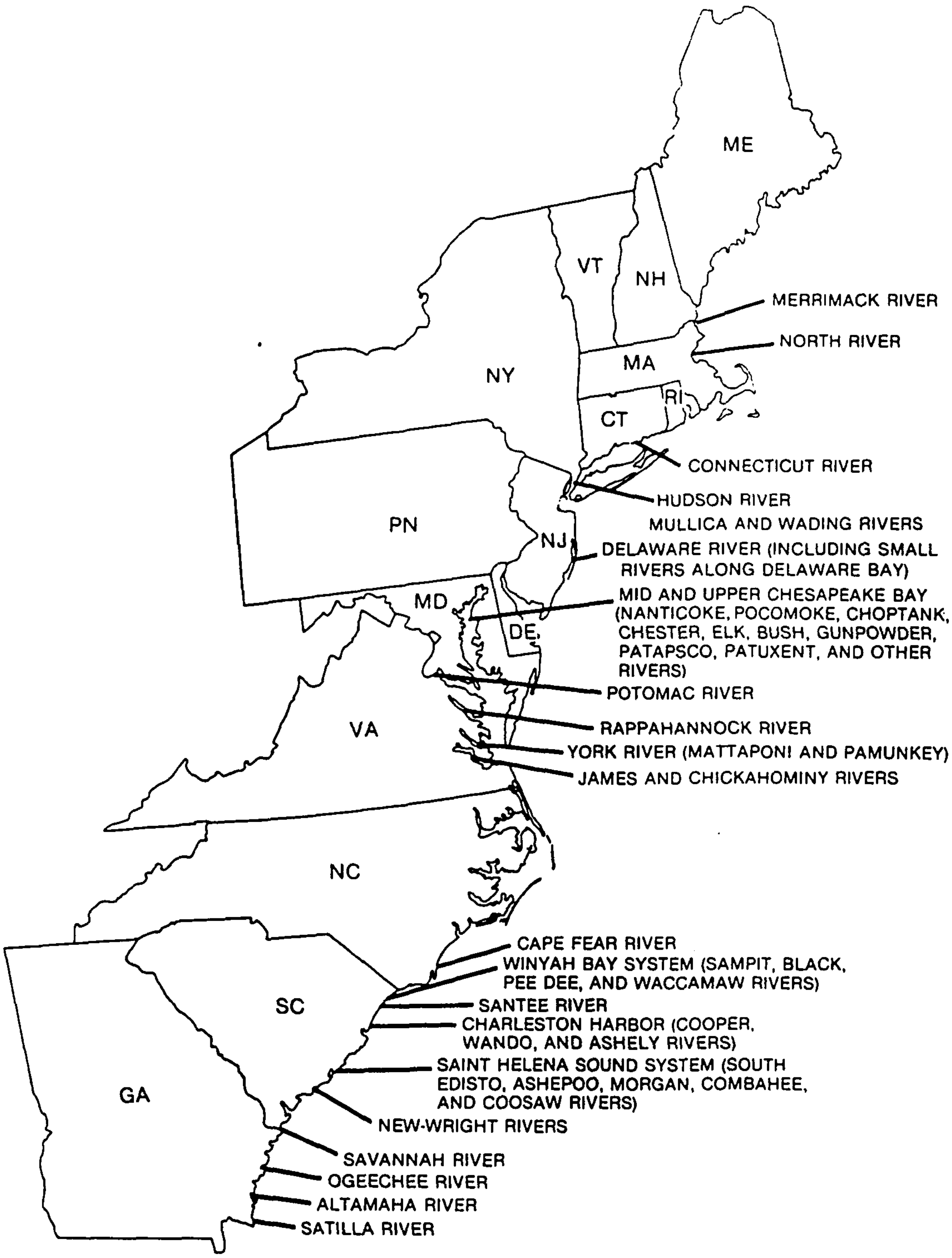
Distribution of Tidal Freshwater Wetlands

Tidal freshwater marshes occur from Maine to Florida (Figure 4) (Odum et al., 1984; Mitsch and Gosselink, 1985). The greatest concentration is found in the mid-Atlantic states (minus North Carolina), South Carolina and Georgia.

Ontogeny of Tidal Marshes

Tidal marshes develop through the interactions among sea level rise, tides, accumulation of organic and inorganic sediments, and growth of macrophytes (Shaler, 1885; Johnson, 1925; Knight, 1934; Chapman, 1960; Adams, 1963; Redfield, 1959, 1967, 1972; Redfield and Ruben, 1962; Orson et al., 1985, Frey and Basan, 1876, 1985). The first published information relating changes in relative sea level and wetland ontogeny

Figure 4. Distribution of tidal freshwater marshes. (from Odum et al., 1984)


ME
VT
NH
MERRIMACK RIVER
NORTH RIVER
MA
NY
RI
CT
CONNECTICUT RIVER
HUDSON RIVER
PN
MULLICA AND WADING RIVERS
NJ
DELAWARE RIVER (INCLUDING SMALL RIVERS ALONG DELAWARE BAY)
MD
MID AND UPPER CHESAPEAKE BAY (NANTICOKE, POCOMOKE, CHOPTANK, CHESTER, ELK, BUSH, GUNPOWDER, PATAPSCO, PATUXENT, AND OTHER RIVERS)
DE
POTOMAC RIVER
RAPPAHANNOCK RIVER
VA
YORK RIVER (MATTAPONI AND PAMUNKEY)
JAMES AND CHICKAHOMINY RIVERS
NC
CAPE FEAR RIVER
WINYAH BAY SYSTEM (SAMPIT, BLACK, PEE DEE, AND WACCAMAW RIVERS)
SC
SANTEE RIVER
CHARLESTON HARBOR (COOPER, WANDO, AND ASHELY RIVERS)
SAINT HELENA SOUND SYSTEM (SOUTH EDISTO, ASHEPOO, MORGAN, COMBAHEE, AND COOSAW RIVERS)
GA
NEW-WRIGHT RIVERS
SAVANNAH RIVER
OGEECHEE RIVER
ALTAMAHA RIVER
SATILLA RIVER

is found in Mudge (1862). Mudge noted tree stumps of certain freshwater wetland trees were positioned in an upright position at the bottom of saltmarsh peat. He concluded that the stumps indicated that the area was once located at an elevation above the mean high tide mark (MHTM). He further noted the presence of salt meadow hay grass (Spartina patens) rootstock below the high water mark, a species normally found growing above the MHTM. Therefore, he hypothesized, that the salt marshes "grew" (i.e. accreted) through the gradual accumulation of salt meadow hay grass rootstock and sediments deposited on the high tides. Mudge (1862) attributed the change in relative sea level to the subsidence of the land via erosion of deep clay subsoils by groundwater flow. Around the same time, Cook (1857) took note of the presence of numerous tree stumps of various species interspersed under the peat layer of salt marshes up and down the east coast of the United States. He also interpreted the presence of the stumps as an indication that the coastland had subsided.

In 1885, Shaler proposed, albeit unknown to him at the time, a rival theory on salt marsh ontogeny (Shaler, 1885). He hypothesized that tidal salt marshes had their ontogeny through eustatic changes in sea level rather than in land subsidence, as suggested by Mudge (1862). His tidal marsh model involved several steps. The first step was increased protection of a shoreline via a barrier island or similar formation that creates low wave energy and tide currents. The process ends with the formation of a smooth cordgrass (Spartina alterniflora) dominated salt marsh and involves the accretion of both autochthonous organic and allochthomous inorganic sediments in the protected areas (Shaler, 1885). Furthermore, he hypothesized that the growth of the marsh would be vertical at a rate equal to the rate of rise of relative sea level and noted that there was a point where the rate of sea level rise could exceed the existing accumulation of sediments of a coastline (Shaler, 1885). As examples, he noted the lack of beach marks prior to 10,000 years before present. Unfortunately, Shaler did not try to explain the presence of high marsh peat (Spartina patens) comprising most of the salt marsh deposits below the high water mark.

Shaler's oversight led Davis (1911) to reject Shaler's theory. Working without the knowledge of Mudge's (now long forgotten) theory, Davis (1911) came to the same conclusions as Mudge (Davis, 1911; Knight, 1934). A number of years after Davis, Johnson (1925) noted that neither Mudge's (1862) and Davis's (1911) hypothesis of coastal subsidence nor Shaler's hypothesis of wetland evolution from open water (1885) were necessarily exclusive of each other (Johnson, 1925; Knight, 1934; Redfield, 1959; Chapman, 1960; Adams, 1963). Instead, Johnson recognized that Shaler's classical theory may account for the beginnings of salt marshes, i.e. primary succession in a classical sense, while that advanced by Mudge (1862) and Davis (1911) met the facts as observed in field studies conducted by Davis (1911) and himself and would represent a maturing process within a salt marsh, i.e. secondary succession processes in response to changes in environmental parameters. He attributes the lack of evidence supporting Shaler's theory to erosion of the facies and/or a lack of proper sediment cores (inaccessable depths) (Johnson, 1925; Knight, 1934).

Ontogeny of Tidal Freshwater Marshes

Unlike the high organic based (peat) soils (>50% organic content) of the marshes of the north east, southern tidal marshes, including tidal freshwater marshes, have less than 50% organic material (Whigham and Simpson, 1976; Odum et al., 1984; Ledwin, 1988; Reay, 1989). This has been attributed to a number of reasons including slower decomposition rates and freezing of the marsh surfaces during winter months in the northern marshes (Frey and Basan, 1976, 1985) and different vegetation and more readily available fluvial sediment resources in tidal freshwater marshes than those found in salt marshes (Odum et al., 1984). Odum et al. (1984) found a typical cross section of a vertical core through a tidal freshwater marsh showed 1) a hard bottom consisting of a Pliestocene erosion surface cut during a glacial period of lowered sea level, 2) varying layers of river, estuarine, and marsh sediments, and 3) a cap of recent tidal freshwater marsh sediments varying in thickness from one to several meters.

Vegetation Patterns of Tidal Freshwater Marshes

The vegetation of tidal freshwater marshes consists of much more diverse flora in contrast to saltwater marshes (Doumlele, 1981; Simpson et al., 1983; Odum et al., 1984; Odum, 1988). Doumlele (1981), working in Sweet Hall Marsh, reported a seasonal change in vegetation with *Peltandra virginica* dominating the cover early in the season with 52% relative cover in July, dropping to 18% by August. The same pattern in *P. virginica* was noted by Whigham and Simpson (1976) and Odum and Haywood (1978). In the late summer and early fall the *P. virginica* of Sweet Hall Marsh was replaced by *Leersia oryzoides*, *Polygonum punctatum*, *Pontederia cordata*, and *Polygonum arifolium* (Doumlele, 1981). However, *P. virginica* dominated the biomass throughout the growing season. Doumlele (1976) reported no obvious vegetation pattern for the Sweet Hall Marsh system but noted the presence of a *Spartina cynosuroides* dominated levee. Odum et al. (1984) described eight major floristic associations occurring in tidal freshwater wetlands from Massachusetts to northern Florida (Table 1)

Effects of Environmental Parameters on Vegetation Patterns

Environmental parameters include climate (Niering and Warren, 1980; Gross, 1986; Frey and Basan, 1976, 1985), energy flow and nutrient dynamics (Teal, 1962; Nixon, 1980; Gross, 1986; Frey and Basan, 1985),

Table 1. Floristic associations (communities) of tidal freshwater marshes from Massachusetts to northern Florida (after Odum et al., 1984).

COMMUNITY TYPE	DOMINANT SPECIES	ZONE
1. Spatter Dock	Nuphar luteum	below MLW
2. Arrow Arum/Pickerelweed	Peltandra virginica Pontederia cordata	cosmopolitan throughout the tidal zone
3. Wild Rice	Zizania aquatica	nearly mono - typic stands above MHW
4. Cattail	Typha angustifolia Typha latifolia	upper inter - tidal zone
5. Giant Cutgrass	Zizaniopsis mileacea Cladium jamaecensis	Predominantly in wetlands south of Va. Above MHW
6. Mixed Aquatic	P. virginica Polygonum spp. Leersia oryzoides plus others	also known as the "mixed" community type Found at or just above
7. Big Cordgrass	Spartina cynosuroides P. virginica P. cordata	Mono - typic stands on levee of oligohaline marshes
8. Bald Cypress/Black Gum	Taxodium distichum Nyssa sylvatica Acer rubrum Fraxinus pennsylvanica	Found in the landward portions of coastal marshes

inter-and intraspecific competition (Johnson and York, 1915; Gross, 1986; Frey and Basan, 1985; Snow and Vince, 1984), and tides and tidal related factors (including sedimentation processes) (Johnson and York, 1915; Johnson, 1925; Adams, 1963; Grey and Bunce, 1972; Mahall and Park, 1976; Gray and Scott, 1977; Niering and Warren, 1980; Gross, 1986; Frey and Basan, 1985; Snow and Vince, 1984; Vince and Snow, 1984).

Climatic Factors:

Climatic factors include prevailing precipitation, temperature, wind patterns and storms (Niering and Warren, 1980; Gross, 1986; Frey and Basan, 1985). They are controlled by atmospheric conditions, geographic location, and the presence of geological structures and/or obstructions (e.g. oceans, mountain ranges, deserts).

Nutrient Budgets:

Nutrient-stressed terrestrial plants can change root-to-shoot ratios, photosynthesis, and root absorption capacity (Chapin, 1980; Gross, 1986).

In a North Carolina salt marsh several researchess have suggested that available iron might differentially limit growth and distribution of marsh plants (Adams, 1963; Mooring et al., 1971). However, Roberts (1976) found no evidence that iron was limiting to Spartina alterniflora distribution.

Nitrogen is known to stimulate S. alterniflora growth (Valiela et al., 1978; Garbisch et al., 1975, Woodhouse, 1979). However, no evidence has been found that nutrient availability alone functions as an important factor in controlling vegetation patterns (Roberts, 1976; Nester, 1977; Mendelssohn, 1979; Niering and Warren, 1980). In fact, in aquatic macrophytes it is still unclear how nutrients resuspended from sediments interrelate to those obtained from the water (Barco and Smart, 1981, Gross, 1986).

Inter-and Intraspecific Competition:

Johnson and York (1915) found that greenhouse grown specimens of Spartina alterniflora, S. patens, and Distichlis spicata reached maximum biomass in low salinity water and concluded that the strong zonation patterns visible in New England salt marshes were at least in part due to interspecies competition. Snow and Vince (1984) found that biotic factors, such as interspecific competition may be more important in some Alaskan moderate to low salinity marshes than are the tidal factors.

Tides and Related Factors:

Tide dependent factors include inundation frequency and duration, soil redox potential, soil pH, and soil salinity (Johnson, 1925; Adams, 1963; Niering and Warren, 1980; Frey and Basan, 1985; Vince and Snow, 1984).

Inundation frequency and duration are critical in determining species density and distribution patterns (Johnson and York, 1915; Chapman, 1960; Adams, 1963; Frey and Basan, 1985). Johnson and York (1915) pointed out that the greater the tide range, the greater its impact would be felt on species distribution in a vertical plane landward from the estuary. They also noted that prolonged periods of submergence would deprive the roots and rhizomes of wetland plants of oxygen (Johnson and York, 1915). It is now known that when a soil is flooded, anaerobic conditions will quickly materialize as the ability of oxygen to diffuse through water is 10,000 times slower than that in air (Greenwood, 1961; Gambrel and Patrick, 1978; Mitsch and Gosselink, 1986).

Salinity has been noted as an important parameter in determining the density and distribution of marsh organisms (Johnson and York, 1915; Chapman, 1960; Reimold and Queen, 1974; Frey and Basan, 1985). Vince and Snow (1984) found that a combination of soil salinity and waterlogging segregated most of the vegetation zones in an Alaskan salt marsh, despite similarity in the soil texture and little topographic relief between the zones.

The response of plants to changes in salinity may be physiological and/or morphological. Michalowski et al. (1989) demonstrated that control of the pathway specifying primary reactions of photosynthesis of a halophytic plant was not affected by increases in salt. They interpreted this as evidence that only fine tuning of the gene expression for enzymes of the photosynthetic light reactions was necessary under conditions (high salinity) which constitute a severe stress for glycophytes. Studies have also shown that the facultative halophyte Mesembryanthemum crytallinum (common ice plant) responded to salt stress by activating the Crassulacean acid metabolism (CAM) pathway (Hofner et al., 1987; Ostrem et al., 1987). Vernon et al. (1988) have further shown that CAM induction is not developmentally induced but environmentally controlled.

Sea Level Rise:

Relative sea level rise is a combination of three factors: eustatic sea level rise (a worldwide rise in the oceans' volume due to thermal expansion and glacial melt), isostasy (elevation changes of areas of a continent due to isostatic movement up or down), and local perturbations (local elevation changes such as subsidence due to large quantities of ground water withdrawal). Over the past century, eustatic sea level has risen 3.9 to 5.9 inches (10 to 15 cm) (Barnett, 1983: Gornits et al., 1982). When added to isotectonic movement and local events, relative sea level rises as high as 3.9 inches $year^{-1}$ (10 cm $year^{-1}$) have been found in some areas of the eastern United States (Environmental Protection Agency, 1987). In the Chesapeake Bay, the historic relative sea level rise rate is highest near the mouth (0.17

inches (4.3mm) $year^{-1}$ in Hampton Roads area] and lowest at inland Bay stations [0.13 inches (3.2mm) $year^{-1}$ in Baltimore, Md.) (Environmental Protection Agency, 1987).

Sedimentation Processes:

Vertical accretion in wetlands is a function of the sedimentation processes of the ecosystem. In response to sea level rise, the rates of accretion determine whether the relative elevation of a wetland will remain stable or undergo increased inundation as a result of sea level transgression. Therefore, the changes that would occur in the physical, chemical, and geological regimes of a wetland will be determined by the sedimentation processes of the system. Since it is the environmental regime of a system which determines the distribution of plant species within a wetland, it follows that the vegetation patterns of a wetland system may be impacted by sea level rise in two distinct ways:

1) where sediment accretion rates keep pace with sea level rise rates. The inundation periodicity of the wetland is relatively unchanged. There would be changes in the vegetation representing a shift in dominance to more salt tolerant species in response to higher salinity stress.
2) where sediment accretion rates do not keep pace with sea level rise rates. Inundation periodicity would increase as

well as salinity stress. Changes would include a shift to plant species that are not only more salt tolerant, but more hydrophytic as well.

For a marine/estuarine wetland to maintain its spatial integrity during rising relative sea level, it is necessary that the sedimentation processes in the wetland system maintain an accretion rate at least equal to the rate of sea level rise (Redfield, 1959, 1967, 1972; Chapman, 1960; Redfield and Ruben, 1962; Adams, 1963; Ovenshine et al., 1976; Froomer, 1980a, 1980b; Delaune et al.,1986; Stevenson et al. 1986). Ovenshine et al. (1976) reported that in ten years a 1 to 1.5m thick intertidal silt layer developed over 18 sq. km in an Alaska fjord in response to local subsidence of the fjord as a result of a 1964 earthquake. Accretion rates lower than the rate of rise in sea level have been reported for the Chesapeake Bay (Stevenson et al., 1986), Atlantic Coast of Virginia (Oertel et al., 1989), and Louisiana Gulf Coast (Delaune et al., 1986). However, tidal marshes often appear to be major deposit sites in coastal systems (Frey and Basan, 1985). Experimental evidence shows that vegetation can slow tidal velocities enough to cause substantial particulate deposition (Gleason et al., 1979). Inorganic sediment accretion has been documented by Penthick (1980), Ranwell (1964), and Postma (1967).

Although initial sediment flux studies suffered from methodological shortcomings (due to inadequate estimates of instantaneous processes) (Nixon, 1980) a fairly clear picture of the geographic patterns of sediment transport of a range of tidal environments in the U.S. and Europe have been developed. These have led to the conclusion that sedimentary processes in marshes are strongly linked to the geomorphic and hydrodynamics of coastlines (Stevenson et al., 1990).

Boon (1978) has mathematically modeled total suspended sediment transport as:

$Q_s = {}_0^T qs \, dt$ where $Q_s =$ TSS (total suspended sediment) transported through a cross section of a tidal creek during interval 0 to T, qs is the instantaneous estimate of TSS transported, and t = time.

Dott (1983, 1988) indicated that it is important to separate episodic sedimentation processes. Episodic sedimentation can result from any event whose magnitude deviates from the norm (on a geological time scale) for a given environment. It can be periodic in a deterministic sense (e.g. tides), in a stochastic sense (e.g storm seasons), or non-periodic. Non-periodic episodic sedimentation events may be the result of earthquakes and volcanism.

In some tidal wetlands, changes in sediment inputs may be more important than eustatic sea level rise in causing past losses of marshes (Stevenson et al.,in press: Marine geology). Thus, future wetland survival may depend as much on particulate inputs to the coastal zone as on the prospects of global rise in sea levels (Stevenson et al.,in press: Marine geology).

OBJECTIVES

Objective

The primary objective of this study was to identify and quantify the spatial and temporal changes in the vegetation pattern of a 60 hectare portion of a tidal freshwater wetland. Short term changes were determined by comparing the results of the vegetation analysis conducted for this study with that of a previous study of the same site. Long term changes in the vegetation associations (also referred to as assemblages by other authors) that comprise the vegetation pattern of the wetland were determined through interpretation of a series of historic and recent aerial photographs. For the purpose of this study, a vegetation pattern is defined as a mosaic of vegetation associations. A vegetation association is defined as a plant community that has a definite floristic composition and a uniform physiognomy and habitat conditions (Mueller-Dombois and Ellenberg; 1974).

Rationale

It has been long recognized that the vegetation pattern of marshes of an estuary change along a salinity and tidal gradient as one moves upstream. Estuarine tides have an initial decrease in height (frictional forces acting on the progressive tide wave) and, depending on topography, usually show a secondary increase in range due to seiche activity (standing waves), as is the case on the Pamunkey River (Figure 01). Salinity decreases upstream as the tidal effect is diminished by frictional factors (Knauss, 1978) and the tidal waters are diluted by freshwater input from the watershed and tributaries (Odum et al., 1984). In response to the decrease in salinity, plant species richness of adjacent tidal wetlands increases (Wass and Wright, 1969).

The above scheme is based on fixed time and varying distance (i.e. movement upstream). However, the same pattern can occur for varying time and a fixed wetland site (i.e. non-varying distance). If the salinity of a site changes over time, the vegetation of that site will change to species more tolerant of the higher salinity. At a site such as Sweet Hall Marsh, a tidal freshwater wetland where species richness is currently high (Doumlele, 1976; 1981), some species would not be able to tolerate the increased salinity and inundation stress and would slowly become less important or even extirpated from the marsh. The result would be a lower species richness and, since a vegetation association is defined in part as a plant community that has a definite floristic composition, a change in the vegetation pattern of the wetland system. In fact, a similar model has been proposed as a response of wetlands to a predicted rise in relative sea level over the next several decades (EPA, 1987). Unfortunately, little is known about the rate of change in the vegetation pattern that could be expected in these wetlands.

Since no studies of Sweet Hall Marsh have been conducted with the intent of long term monitoring of vegetation association changes in mind, the main purpose of this study was to establish such a data base. The information gathered from this study provides the data base necessary to detect subtle changes over the course of years and/or decades.

There is a need to develop an analysis protocol to provide useful long term analysis and data gathering. Once established, comparisons of future work using similar methods would be productive and efficient. The protocol would be useful not only for new information, but for the information that can be salvaged from the limited historical data base.

HYPOTHESIS

Hypothesis

The hypothesis of this study is that changes in the vegetation pattern in Sweet Hall Marsh may be seen through analysis of the vegetation associations of the marsh. Through repeated analysis over time, these changes can be measured. These changes are due to shifts in the dominance of individual plant species toward species that are more adapted to changes in the estuarine environmental parameters.

Rationale

The vegetation pattern of a wetland is dependent upon the environmental and biological parameters of a system (Snow and Vince, 1984; Vince and Snow, 1984; van der Valk, 1981, 1987; and others). Important environmental parameters include inundation periodicity (tides, flooding, etc.), water chemistry (presence of salts, nutrients, etc.), edaphic conditions, and climate (length of growing season, precipitation, ambient temperatures, etc.). Biological parameters include plant propagule availability, life history and competitive ability as well as grazing and parasite pressure. Variation in either type of parameter may bring about changes in vegetation associations. These changes can occur over varying time scales from days (e.g. as a result of stochastic events) to months (e.g. in response to grazing) to years (e.g. from propagule availability or sea level rise). It is the long term changes (i.e those that occur over years or decades) that may occur in wetland vegetation patterns that are of interest to this study. The types of changes that can occur are changes in morphology (e.g. broadleaf, none persistent to graminoid persistent), physiography (e.g. levee formation), fecundity (the ability of a wetland to reproduce), and/or increases or decreases in diversity

The rate of rise in relative sea level has been well documented for the Chesapeake Bay (Hicks, 1972, 1978; Barnett, 1983; EPA, 1987). Associated with the rise are changes in environmental parameters of the estuary, including salinity and tidal inundation. As the environmental parameters change, plant species must adjust to the new environment. Those that can not adjust will be extirpated from the wetland. The extirpation of a species provides potential habitat space for a more tolerant species. Species may come from external (allocthonous) or internal (autocthomous) propagule sources.

As the stresses increase, the species richness of a wetland should decline as only the most tolerant species would survive. In theory, this stress effect should be seen first in areas of the wetland that are directly exposed to the changes, i.e. creekbanks and areas behind them that are directly under the influence of the incoming tides. In a classical sense, sediment deposition would be highest in the levee areas due to the energy abatement action of the vegetation. Since less water born sediment reaches the inland portion of the marsh, these areas must rely upon stochastic events and refracted organic processes to change or maintain marsh surface elevations. Therefore, there would be non-uniform response across the wetland to forcing functions. Distance from a major river/creek and physiography would play a major role.

Thus, location and inundation periodicity are important parameters in the composition of vegetation patterns and associations. A better understanding of plant/elevation relationships and plant phytogeography in a wetland helps to make it possible to identify the response of vegetation associations to environmental conditions.

METHODS

I. VEGETATION PATTERN OF SWEET HALL MARSH

Flora

All species occurring in the study transects were identified to species level. Taxonomic nomenclature follows Kartesz and Kartesz, 1980.

Vegetation Parameters

Two different sets of field data were required to supply the information necessary to reach the objectives of this study. The first set of data, provided by systematically arranged cover-plots, described in detail the spatial array of vegetation assemblages of Sweet Hall Marsh. The second set, provided by random clip-plots, quantified the changes in vegetation patterns over time.

Cover-Plots: Data were collected from 1m x 1m plots arranged at ten meter intervals along each of seven transects (see below for placement of transects) on each of the collecting dates (Table 2). The plot boundaries were delineated by a 1m x 1m frame made of 1 inch PVC pipe. Care was taken to avoid walking in the plots and to use alternate walkways to avoid creating paths along the transects.

Clip-Plots: Forty random points, ten on each of four transects (see below for placement of transects), were established in the marsh. On each of the seven collection dates (Table 2) another random point was chosen for each of the forty points. The latter was comprised of two

Table M2. Field collection dates for Sweet Hall Marsh vegetation study, 1987.

SAMPLE DATE	DRYING DATE
APRIL 11-19	APRIL 22- MAY 1
MAY 13-21	MAY 23- JUNE 2
JUNE 13-21	JUNE 23- JULY 2
JULY 13-21	JULY 23- AUGUST 1
AUGUST 12-20	AUGUST 24 - SEPTEMBER 2
SEPTEMBER 12-20	SEPTEMBER 23- OCTOBER 2
OCTOBER 12-20	OCTOBER 23- NOVEMBER 1

numbers and represented the northeast corner of the area to be used for the clip-plot. The first number was either a zero (0) or one (1) and determined the side of the transect on which the clip-plot would be taken (zero (0) = west and one (1) = east). The second number ranged from one (1) to ten (10) and denoted the number of meters east or west a clip-plot would be taken from the transect. A record was kept of the location of each previous clip-plot to avoid repeats at a later collection date. Care was taken during each collecting date not to disturb potential future clip-plots by measuring distances and establishing walking areas a minimum of one meter south of the random point location on the transect. A 0.5m x 0.5m ($0.25m^2$) frame made of 1 inch diameter PVC pipe was used to delineate the clip-plots boundaries. Before clipping, cover and stem density was recorded for each species within the clip-plot.

Placement of Transects:

Seven transects, all running south to north, were established on site. Four were used for collection of both clip-plot and cover-plot data and three for cover-plot data only.

Three of the clip-plot transects were re-occupied from a previous vegetation study (Doumlele, 1976). A fourth transect used in that study had been heavily damaged by erosion in the past decade and, therefore, could not be re-occupied. To replace the erosion damaged transect a fourth transect was chosen in an area of the marsh that was similar in vegetation composition to the remaining eroded transect. Furthermore, emphasis was placed on using a site that would produce data for correlation of the vegetative patterns from that site with hydrologic data collected in a concurrent study (Reay, 1989).

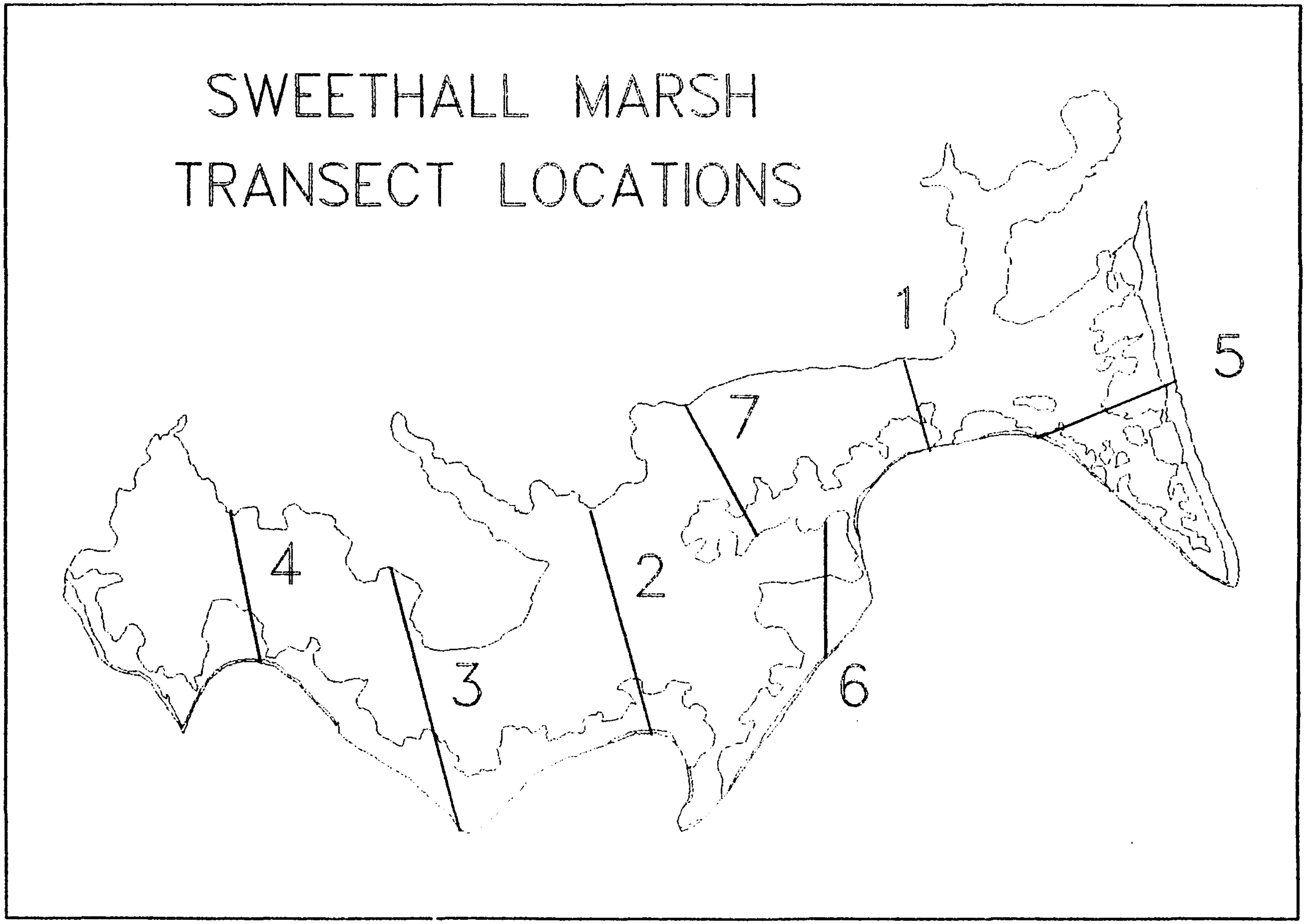
The locations of the three cover only transects were selected to provide for complete representation of existing vegetation assemblages within the 50 ha. study area. This was accomplished by identifying and ground truthing recognizable signatures and assuring that these signatures were adequately covered by a minimum of one transect.

1986 low-level (500ft.) aerial photographs as well as field surveillance were used to assure the four new transects met their respective criteria. The final locations of the seven transects are shown in Figure 5.

Data Collection:

Cover (collected from both cover- and clip-plots): Although there are several cover class techniques available, there are few differences among them (Mueller-Dombois and Ellenberg, 1974). The modified Daubenmire technique was chosen for its ease of application and consistency in the field (Daubenmire 1959; 1966; 1968). Percentage of ground cover was used to estimate individual species coverage in both the cover - and clip-plots. In each plot a number was assigned to individual species within the plot according to the percentage of the

Figure 5. Location of vegetation transect lines.


SWEETHALL MARSH
TRANSECT LOCATIONS
1
5
7
4
2
3
6

area within the plot that the species covered. The percentage (%) of each species was then assigned to a cover class (Table 3). The mid-point of the respective cover class for each individual species was used to represent "cover" in the calculations of the descriptive and quantitative vegetation parameters (see below). The cover classes have been arranged in such a way that human error and variation becomes minor and does not affect the outcome of the data (Mueller-Dombois and Ellenberg 1974). Cover scale designations, ranges and midpoints are given in Table 3. Since individual species populations were recorded and mid-point ranges were used, it was possible for a plot to have greater than 100% cover.

Frequency (collected from clip-plots only): Frequency is a measure of presence/absence of a species. In this study it is indirectly measured when cover data is taken. For each clip-plot on a transect, the list of species that have cover values in the plot represented a count of one (1) for each species. To find the frequency of individual species, the total number of times that species occurred on one collecting date is divided by the sum of all species occurrences in all plots for that date.

Density (collected from clip-plots only): The total number of stems of an individual species that occurs in all clip-plots per collecting date represents the density of that species for that date.

Table M1. Vegetation cover scale (modified from Daubenmire, 1959; 1968).

COVER CLASS	RANGE OF COVER %	CLASS MIDPOINTS %
6	96-100	97.5
5	76-95	85.0
4	51-75	62.5
3	26-50	37.5
2	6-25	15.0
1	1-5	2.5
T(trace)	>1<0	0.1

Only stems that were rooted in the clip-plots were counted. Vegetation not rooted within a plot but hanging into it (therefore receiving a cover value) would have a density of zero (0).

For comparative purposes, analysis of the field data followed that developed by Doumlele in a previous vegetation analysis of the study site (Doumlele, 1976).

Relative frequency, relative density, and relative dominance (using the midpoints of the cover categories) was calculated by the following the formulas:

$$\text{Relative frequency} = \frac{\text{Species frequency}}{\text{Sum of the frequency values for all species}} \times 100,$$

$$\text{Relative density} = \frac{\text{Number of individuals of the species}}{\text{Number of individuals of all species}} \times 100,$$

$$\text{Relative dominance} = \frac{\text{Species coverage}}{\text{Sum of coverage values for all species}} \times 100.$$

Species importance values are the sum of the above three parameters (Curtis and McIntosh, 1950; Phillips, 1959; Mueller-Dombois and Ellenberg 1974). Species diversity was calculated using the Shannon-Weaver index (Shannon and Weaver, 1949) where:

$$\underline{H} = -\Sigma P_i \log P_i$$

where: $\underline{H}$ the diversity index; and

P_i is the importance probability (individual species IV divided by total IV) of each species.

H was calculated by month for each clip-plot taken during the study. The similarity of the species content of the two studies was measured with a Sorenson's similarity index (Kontkanen, 1957):

$$QS = \frac{2c}{a + b} \times 100$$

where QS = Sorenson's index,

a = number of clip plots in which species A occurred;

b = number of clip plots in which species B occurred; and

c = number of clip plots in which both species occurred.

All possible combination were checked. A dendrogram was prepared with the results obtained from a weighted pair-group cluster analysis (Sokal and Sneath, 1963).

Vegetation Mapping

Vegetation mapping of the present assemblages was accomplished using aerial photography taken at 500 ft. during the early fall of 1986. Each 9 in. x 9 in. photograph was covered with prepared acetate and the dominant vegetation patterns delineated. Identification of the patterns was done by analysis of the cover-plot field data and general ground truthing of the photographs. At least four wetland types were delineated: creek bank, levee, high marsh and mixed marsh. Where possible, these four broad categories were further divided into subtypes. Terrestrial, open water, creek and forested wetland boundaries were also denoted.

II. VEGETATION CHANGES

Comparison with Previous Study

Importance values (IV) of the ten highest species from Doumlele (1976) were statistically compared with their IV for this study using a paired t-test.

Seasonal species diversity, evenness, and richness from Doumlele (1976) were statistically compared with the seasonal species diversity, evenness, and richness calculated for this study using a paired t-test.

Interpretation of Aerial Photographs

A vegetation pattern chronology was developed for the site through interpretation of historical aerial photographs. Five historic aerial photographs dating from 1938 to 1976 have been located for the Sweet Hall marsh study site. The vegetation assemblages of each photograph were identified and the changes between subsequent years quantified.

III. ENVIRONMENTAL PARAMETERS

Salinity

The data used for this analysis was collected in 1974 through 1986 by the Virginia Institute of Marine Science in what is refered to as the York River slack water study. Only the data from station 22.73, located on the west of Sweet Hall Marsh, and in the top one meter of the river's surface were used.

Elevations

An Omni Total Station was used to determine the relative elevations of the cover-plots where accessible. All turning points and bench marks were referenced to the 0.00 point on the tide staff. A 10cm diameter rigid, plastic foam float device, flat on the bottom, was attached to the bottom of a surveyor's rod to minimize errors which may otherwise occur by sinking of the rod into the soft sediments.

Tides and Inundation Periodicity

A Fisher-Porter tide gauge was set up on site to provide a set of meteorological tide records of the Sweet Hall Marsh system. A tide staff was established on the east side of the marsh next to the gauge and the gauge referenced to a 0.00 mark on the staff. From these records tidal constituents were extracted using a modified version of HAMEL (Evans, personal communication, 1988). The constituents were used to generate predicted astronomical tides specific to Sweet Hall Marsh. This version of the program represents a modification of the original program (Boon and Kiley, 1978) in that it combines the use of both inference formulas (Schureman, 1958) and the method of least squares (Horn, 1960).

Relative mean sea level (RMSL), mean tide level (MTL), mean high water (MHW), mean low water (MLW), and the range of the tide at the gauge station were calculated and established using a method of simultaneous comparison (Appendix I) (Boon and Lynch, 1972; Boon, personal communication, 1988). The 19 year tide record established at Gloucester Point, Virginia was used for a reference elevation in transferring the sea level (Boon, personal communication, 1988). All levels were then referenced to the 0.00 mark on the tide staff. A conceptual view of the process is given in Figure M1.

The inundation period for each dominant species was calculated as the number of hours per year that a given elevation was covered with water. To accomplish the inundation calculation a computer program was developed that uses the astronomical tide of the area as a height of the water (H_1), subtracts that height from the appropriate elevation (H_2), and, if the former is larger than the latter ($H_1 > H_2$), engages a numerical counter. The counter disengages when H_1 is less than or equal to H_2.

RESULTS

I. VEGETATION PATTERN OF SWEET HALL MARSH (1987)

Flora

60 vascular plant species representing 28 plant families occurred in the clip- and cover-plots (Table 4). All of the species are designated as wetland indicator species in the National Wetland Plant List of Virginia (Reed, 1988).

In general, broad leaved herbaceous and graminoid (grass like) species dominated the wetland. Shrubs and trees were poorly represented and only one tree species (Acer rubrum) actually occurred in a data plot.

Vegetation Parameters

The importance values (IV) of the species occurring in the clip-plots are given in decending order in Table 5. Peltandra virginica had the highest IV (86.3) and Echinochloa crusgalli the lowest (0.1). To remain consistent with Doumlele's 1974 study (Doumlele, 1976) and in consideration of limitations in the sampling design (i.e. not sampling for the rarer species) only the ten species with the highest IV's were analyzed. For future reference the frequency, cover, density, relative frequency, relative cover, relative density, IV and diversity for all species per collecting date are given in Appendix 1.

Peltandra virginica was the most abundant and persistent

Table 4. List of plants species by family, with common names, that occurred in cover quadrats and/or clip plots. A six letter computer code used for analysis precedes each species.

PTERIDOPHYTA (ferns)

Aspidiaceae
- OnoSen = Onoclea sensibilis L.; sensitive fern
- ThePal = Thelypteris palustris Schott; marsh fern

Osmundaceae
- OsmReg = Osmunda regalis L.; royal fern

SPERMATOPHYTA (flowering plants)

Aceraceae
- AceRub = Acer rubrum L. (D.) red maple

Alismataceae
- SagLat = Sagittaria latifolia var. latifolia Willd.; duck potato

Amaranthaceae
- AmaCan = Amaranthus cannabinus (L.) J.D.Sauer; water hemp

Anacardiaceae
- ToxRad = Toxicodendron radicans (L.) Kuntze; poison ivy

Apiaceae
- CicMac = Cicuta maculata L.; water hemlock
- SiuSua = Sium suave Walt. water parsnip

Araceae
- AcoCal = Acorus calamus L.; sweet flag
- PelVir = Peltandra virginica (L.)Schott; arrow-arum

Asclepiadaceae
- AscInc = Asclepias incarnata L.; marsh milkweed

Asteraceae
- AstVim = Aster vimineus var. vimineus Lam.; marsh aster
- BidCor = Bidens coronata (L.)Britt.; beggers-tick
- BidLae = B. laevis (L.)B.S.P.; beggers-tick
- MikSca = Mikania scandens (L.) Willd.; climbing hempweed
- SonAsp = Sonchus asper (L.) Hill; spiny leaved sow thistle
- VerNon = Vernonia noveboracensis (L.) Michx.; ironweed

Table 4. (cont.) List of plant species.

Balsaminaceae
ImpCap = Impatiens capensis Meerb.; jewelweed

Commelinaceae
AneKei = Aneilema keisak Hassk.; Carl's rumflower

Convolvulaceae
CalSep = Calystegia sepium (L.) R.Br.; marsh morning glory

Cyperaceae
CarHya = Carex hyalinolepis Steud.; sedge
CarStr = Carex stricta var. stricta Lam.; sedge
CypStr = Cyperus strigosus L.; marsh sedge
EleQua = Eleocharis quadrangulata (Michx.) Roemer & Schultes; four-sided spikerush
EleFal = Eleocharis falax Weatherby; spikerush
SciAme = Scirpus americanus Pers.; american three-square
SciRob = Scirpus robustus Pursh; saltmarsh three-square
SciTab = Scirpus tabernaemontanii (= S. validus) K.C. Gmel.; soft-stem bulrush

Fabaceae
ApiAme = Apios americana var. americana Medic.; ground peanut
CasFas = Cassia fasiculata Michx.; partridge pea

Iridaceae
IriVir = Iris virginica var. virginica L.; blue flag

Lamiaceae
TeuCan = Teucrium canadensis var. canadensis L.; marsh teucrium

Lythraceae
DecVer = Decodon verticillatus (L.)Ell. water loosestrife

Malvaceae
HibMos = Hibiscus moscheutos L.; marsh mallow
KosVir = Kosteletskya virginica (L.) Presl ex Gray; seaside mallow

Poaceae
CinAru = Cinna arundinacea var. arundinacea L.; cinna
EchCru = Echinochloa crusgalli (L.) Beauvois; barnyard grass
EchWal = Echinochloa walteri (Pursh) Heller; Walter's millit
EriGig = Erianthus giganteus (Walt.) Muhl.

Table 4 (cont.). List of plant species.

Poaceae (cont.)

LeeOry = Leersia oryzoides (L.)Sw.; rice cutgrass
PanVir = Panicum virgatum L.; panic grass
PhrAus = Phragmites australis (Cav.) Trin. ex Steud.; tall reed grass
SpaAlt = Spartina alterniflora Loisel.; smooth cordgrass, salt cordgrass
SpaCyn = Spartina cynosuroides (L.)Roth; tall cordgrass
ZizAqu = Zizania aquatica L.; northern wildrice
ZizMil = Zizaniopsis miliacea (Michx.) Doell & Aschers; southern wildrice

Polygonaceae

PolAri = Polygonum arifolium L.; narrow leaved tear-thumb
PolPun = Polygonum punctatum Ell.; knotweed
PolSag = Polygonum sagittatum var. sagittatum L.; tear-thumb
RumVer = Rumex verticillatus L.; swamp-dock

Pontederiaceae

PonCor = Pontederia cordata L.; pickeral weed

Ranunculaceae

ThaPub = Thalitrichum pubescens Pursh; rue

Rosaceae

RosPal = Rosa palustris Marsh.; swamp rose
Rub_sp = Rubus cunifolius Pursh; blackberry

Rubiaceae

GalObt = Galium obtusum Bigelow; marsh cleaver

Typhaceae

TypAng = Typha angustifolia L.; narrow leaved cat-tail
TypLat = Typha latifolia L.; broad leaved cat-tail

Urticaceae

BoeCyl = Boehmeria cylindrica var. cylindrica (L.) Sw.; false nettle

Violaceae

Vio_sp = Viola sp.; violet

Table 5. Ranking by annual mean importance value of macrophytes of Sweet Hall Marsh for this study. An alphabetic list of species codes is given in Appendix II. IV's were calculated only for the species which occurred in the clip-plots.

RANK	SPECIES CODE	MEAN IV
1	PelVir	86.34
2	LeeOry	58.61
3	ZizAqu	30.42
4	SpaCyn	36.15
5	CarHya	21.47
6	PolPun	16.65
7	BidLae	9.41
8	CarStr	6.22
9	EchWal	5.81
10	AmaCan	4.62
11	PonCor	4.28
12	RumVer	3.41
13	PolAri	3.23
14	AneKei	2.85
15	TypAng	2.41
16	PolSag	2.27
17	EleQua	2.22
18	PhrAus	1.87
19	SciTab	1.51
20	BidCor	1.26
21	TeuCan	1.07
22	OsmReg	1.02
23	HibMos	0.89
24	CicMac	0.78
25	SpaAlt	0.75
26	EleFal	0.62
27	CalSep	0.51
28	MikSca	0.46
29	CasFas	0.34
30	CinAru	0.29

Table 5 (cont.). Ranking by annual mean importance value of macrophytes.

RANK	SPECIES CODE	MEAN IV
31	ThePal	0.26
32	SciAme	0.25
33	AstVim	0.25
34	ThaPub	0.25
35	SciRob	0.23
36	ImpCap	0.21
37	BoeCyl	0.14
38	PanVir	0.12
39	AscInc	0.09
40	GalObt	0.09
41	IriVir	0.08
42	SagLat	0.07
43	RosPal	0.07
44	SiuSua	0.07
45	EchCru	0.06

species throughout the study and occurred in 100% of the quadrats sampled (Table 6). Plotting of the relative cover of each quadrat along the transects shows that there is also an evenness in the distribution of the P. virginica (Figures 6 to 12). Leersia oryzoides had a mean annual frequency of 74.4% (Table 6) and unlike the P. virginica, showed an uneven distribution along the transects (Figures 13 to 19). Zizania aquatica had a mean annual frequency of 32.9% (Table 6). Distribution of Z. aquatica indicates a preference for the mixed marsh zones away from any levees (Figures 20 to 26). Spartina cynosuroides, on the other hand, showed an affinity for the levees (Figures 27 to 33). S. cynosuroides had a mean annual frequency of 41.8% (Table 6). Carex hyalinolepis had a mean annual frequency of 32.7% (Table 6) but was found in only four (4) of the seven (7) transects. Its distribution appears scattered (Figures 34 to 37). Polygonum punctatum had a mean annual frequency of 35.8% (Table 6) and had an uneven distribution (Figures 38 to 44). Bidens laevis, with a mean annual frequency of 22.9% (Table 6), also occurred only in four of the seven transects and had an uneven distribution pattern (Figures 45 to 48). Carex stricta had a mean annual frequency of only 6.6%, lowest of the ten species (Table 6). It was found in five of the seven transects and had a spotty (i.e. small dense populations wide spread in distribution) (Figures 49 to 53). Echinochloa walteri had a

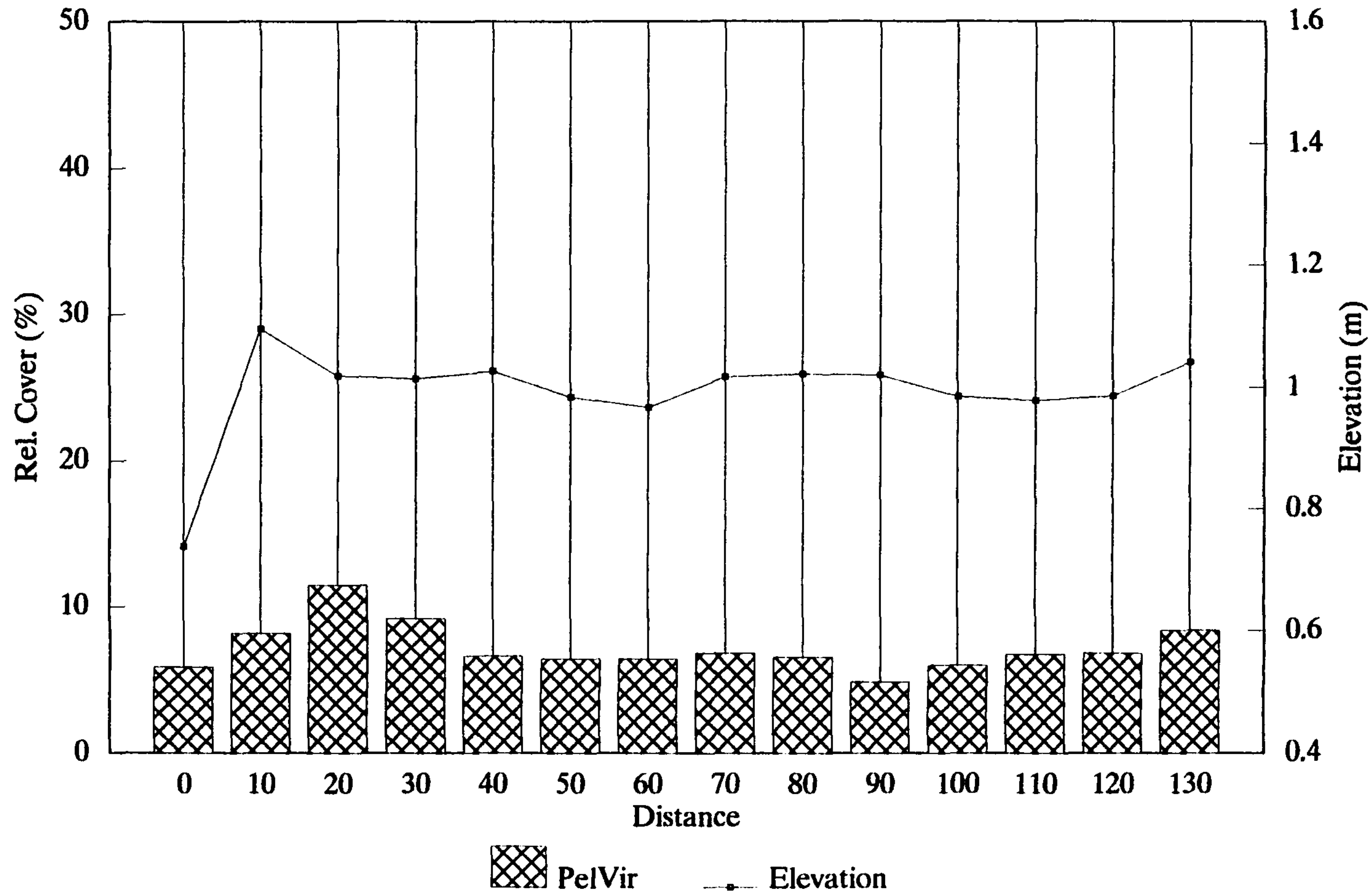
Table 6. Frequency distribution of ten species with highest importance value for this study.

SPECIES	APR	MAY	JUN	JUL	AUG	SEP	OCT	X
Peltandra virginica	100	100	100	100	100	100	100	100
Leersia oryzoides	87.5	77.5	85.7	77.5	77.5	50.0	65.0	74.4
Zizania aquatica	0	0	42.9	0	62.5	80.0	45.0	32.9
Spartina cynosuroides	37.5	42.5	42.9	40.0	40.0	50.0	40.0	41.8
Carex hyalinolepis	30.5	22.5	71.4	22.5	22.5	20.0	40.0	32.7
Polygonum punctatum	67.5	30.0	42.9	45.0	30.0	20.0	15.0	35.8
Bidens laevis	12.5	45.0	2.6	52.5	37.5	0	10.0	22.9
Carex stricta	9.0	7.5	0	10.0	15.0	0	5.0	6.6
Echinochloa walteri	0	45.0	0	10.0	12.5	30.0	15.0	16.0
Amaranthus cannabinus	5.0	30.0	14.3	40.0	27.5	0	0	16.7

Figure 6. Distribution of PelVir along transect 1.

DISTRIBUTION OF PelVir

TRANSECT 1

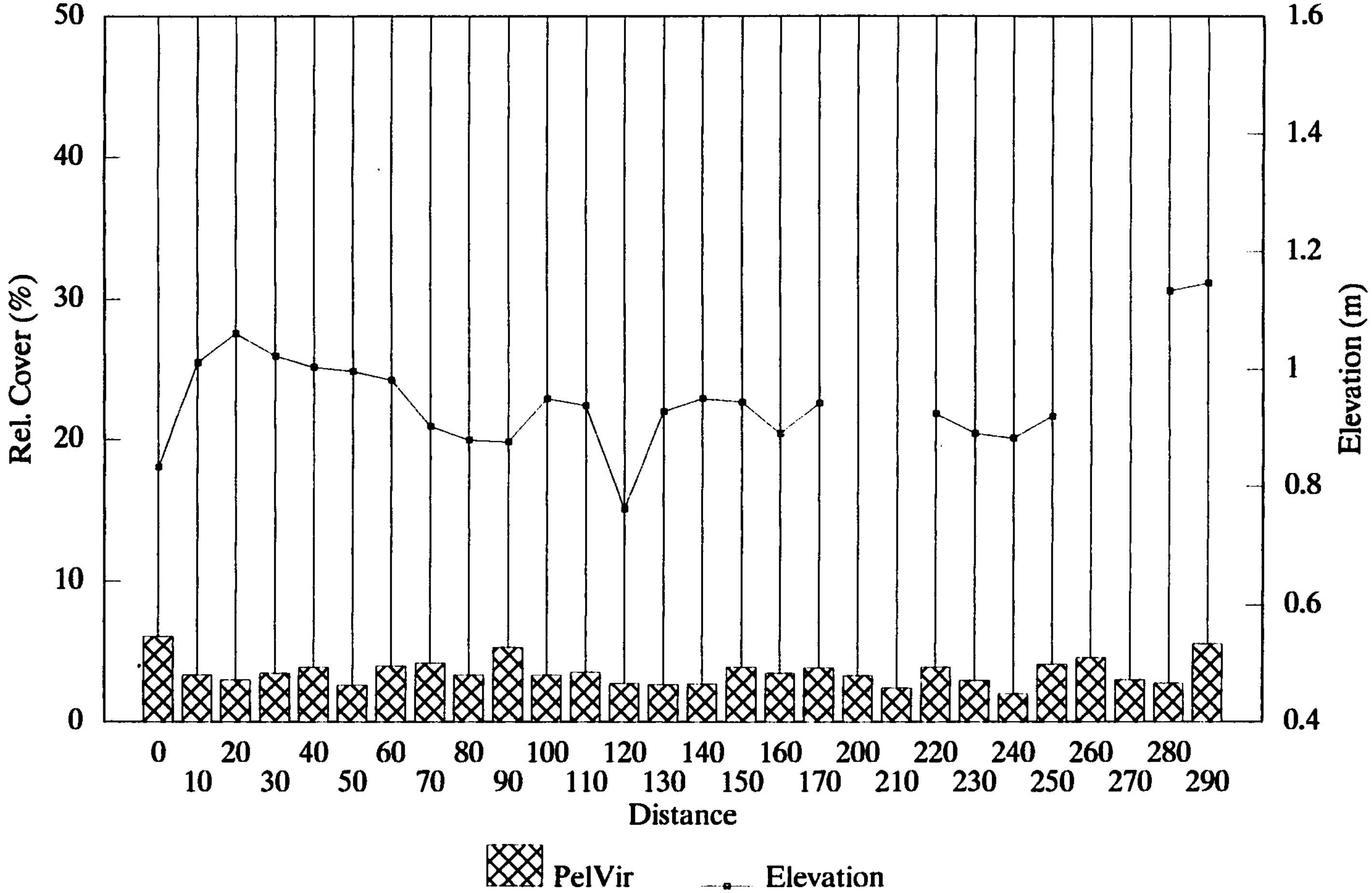


Note: Distance is measured in meters from the creek.

Figure 7. Distribution of PelVir along transect 2.

DISTRIBUTION OF PelVir

TRANSECT 2

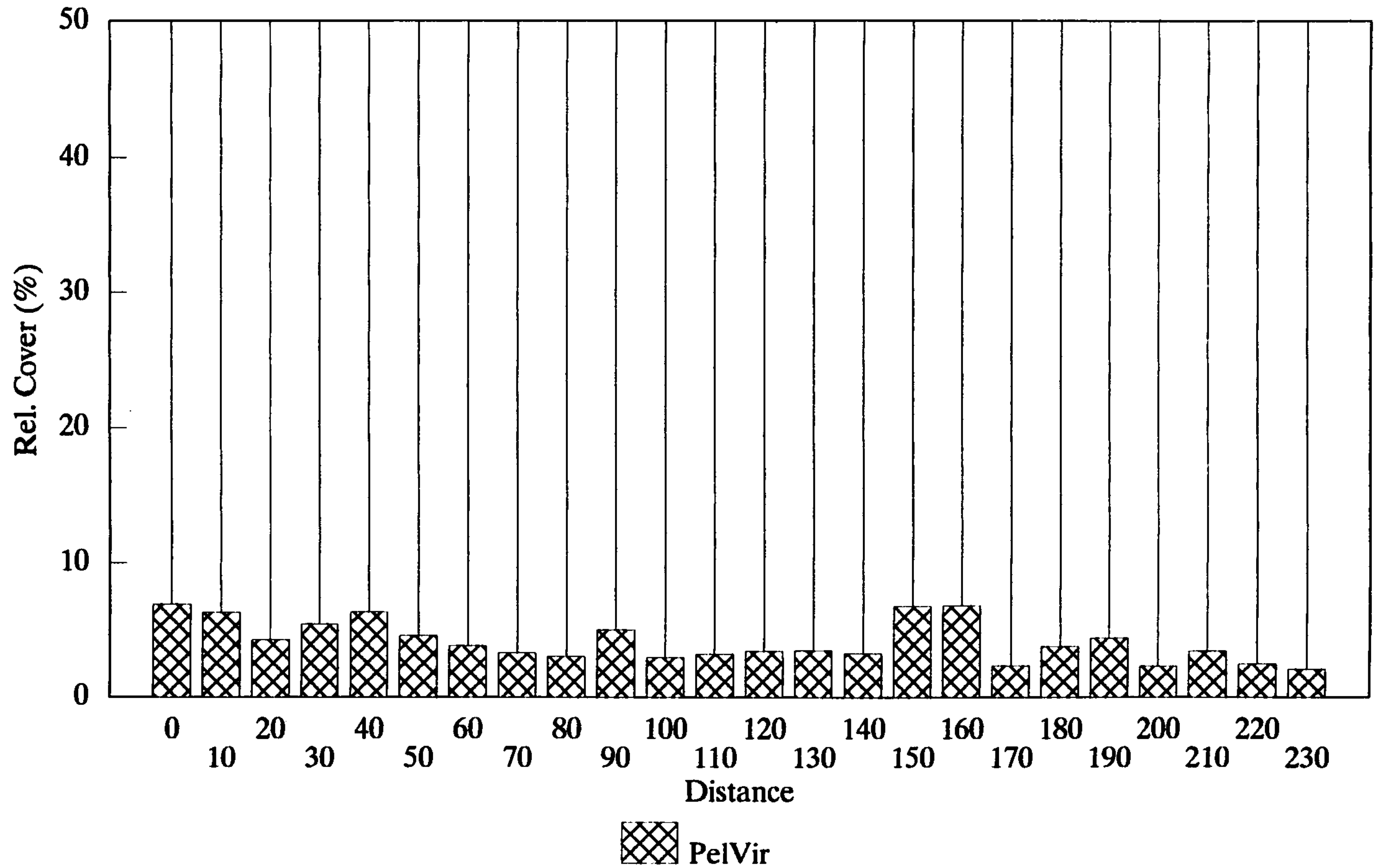


Note: Distance is measured in meters from the creek.

Figure 8. Distribution of PelVir along transect 3.

DISTRIBUTION OF PelVir

TRANSECT 3

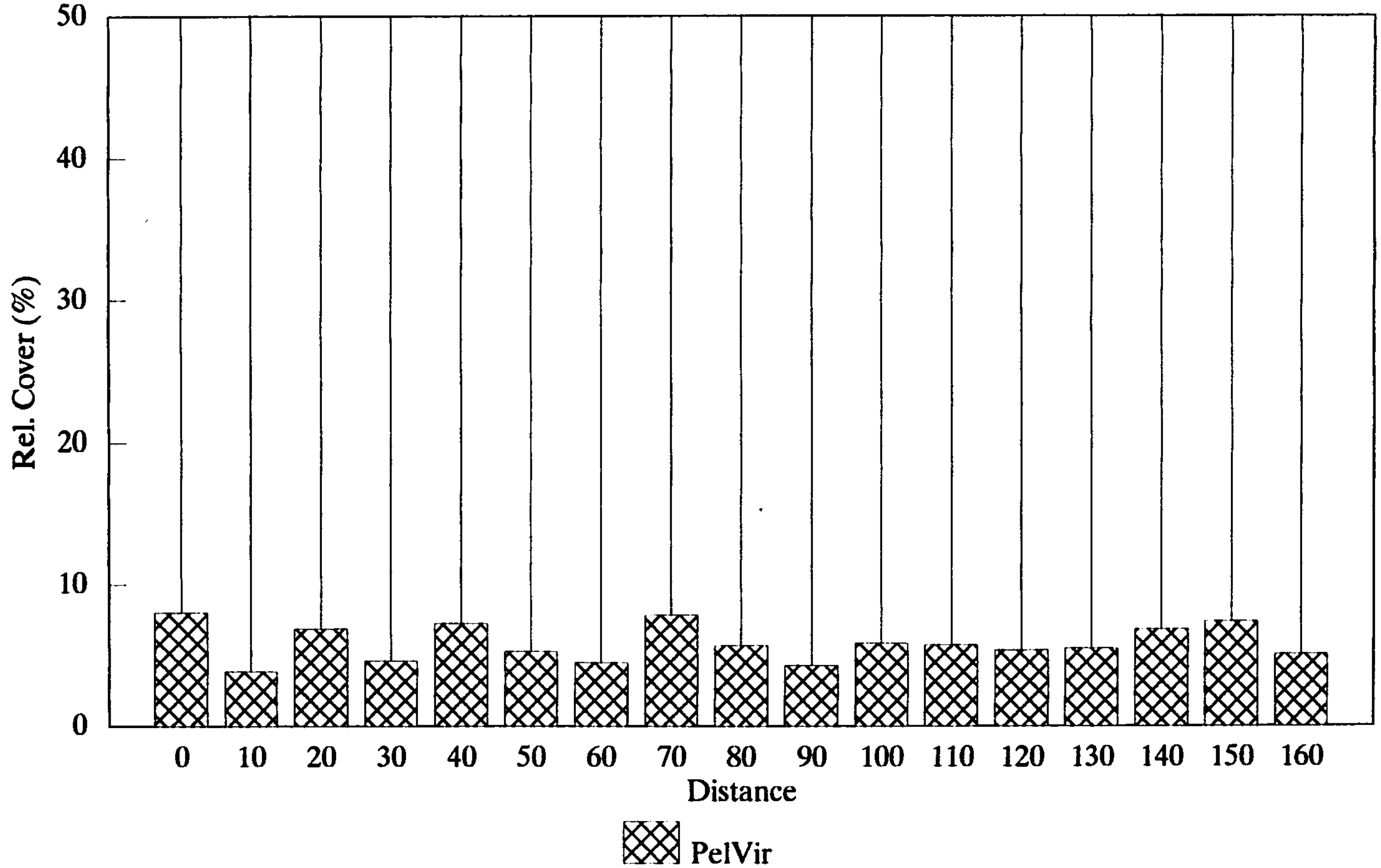


Note:1.Distance is measured in meters from the creek.
2. No elevation data available for this transect.

Figure 9. Distribution of PelVir along transect 4.

DISTRIBUTION OF PelVir

TRANSECT 4

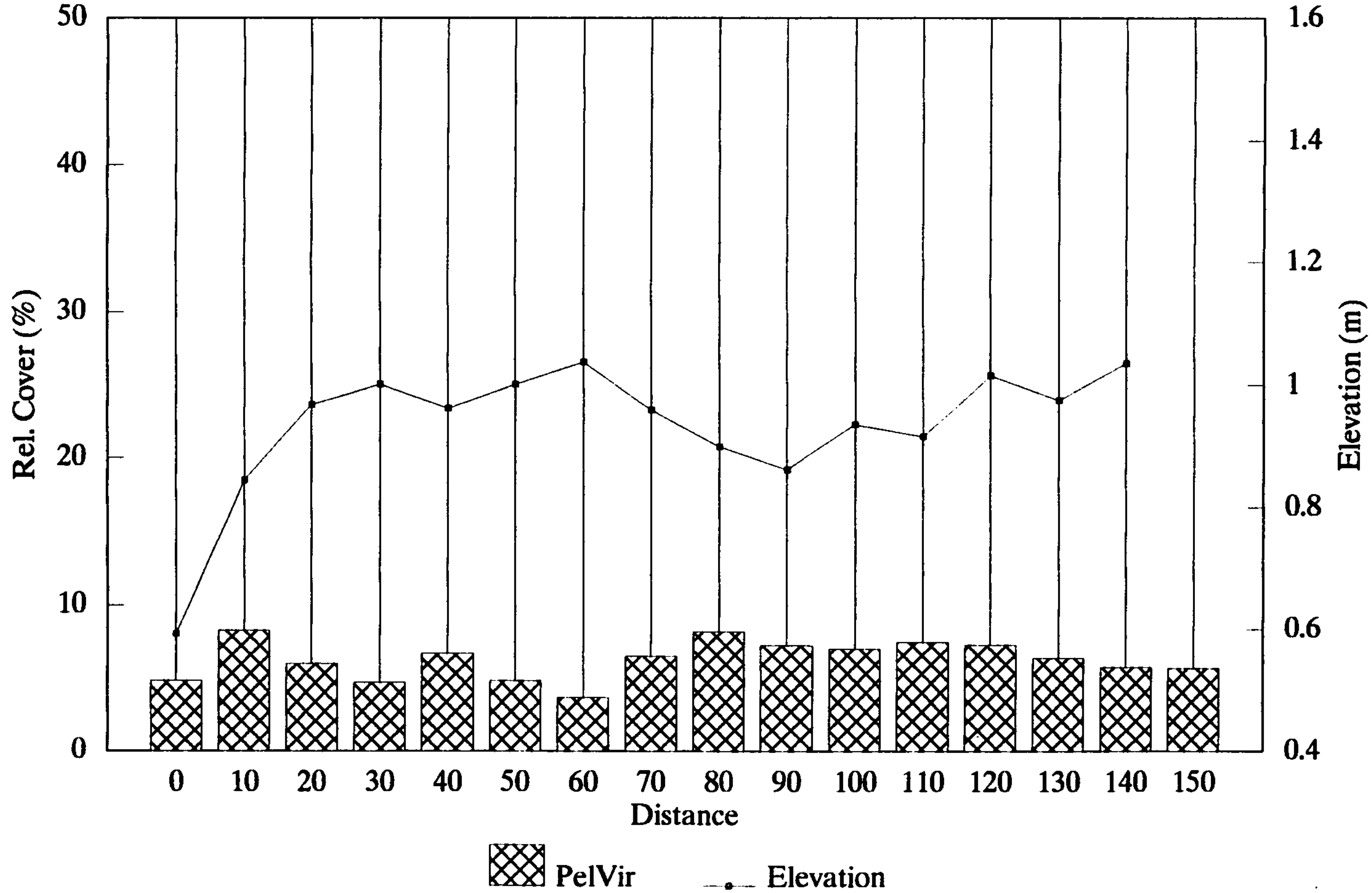


Note:1.Distance is measured in meters from the creek.
2.No elevation data available for this transect.

Figure 10. Distribution of PelVir along transect 5.

DISTRIBUTION OF PelVir

TRANSECT 5

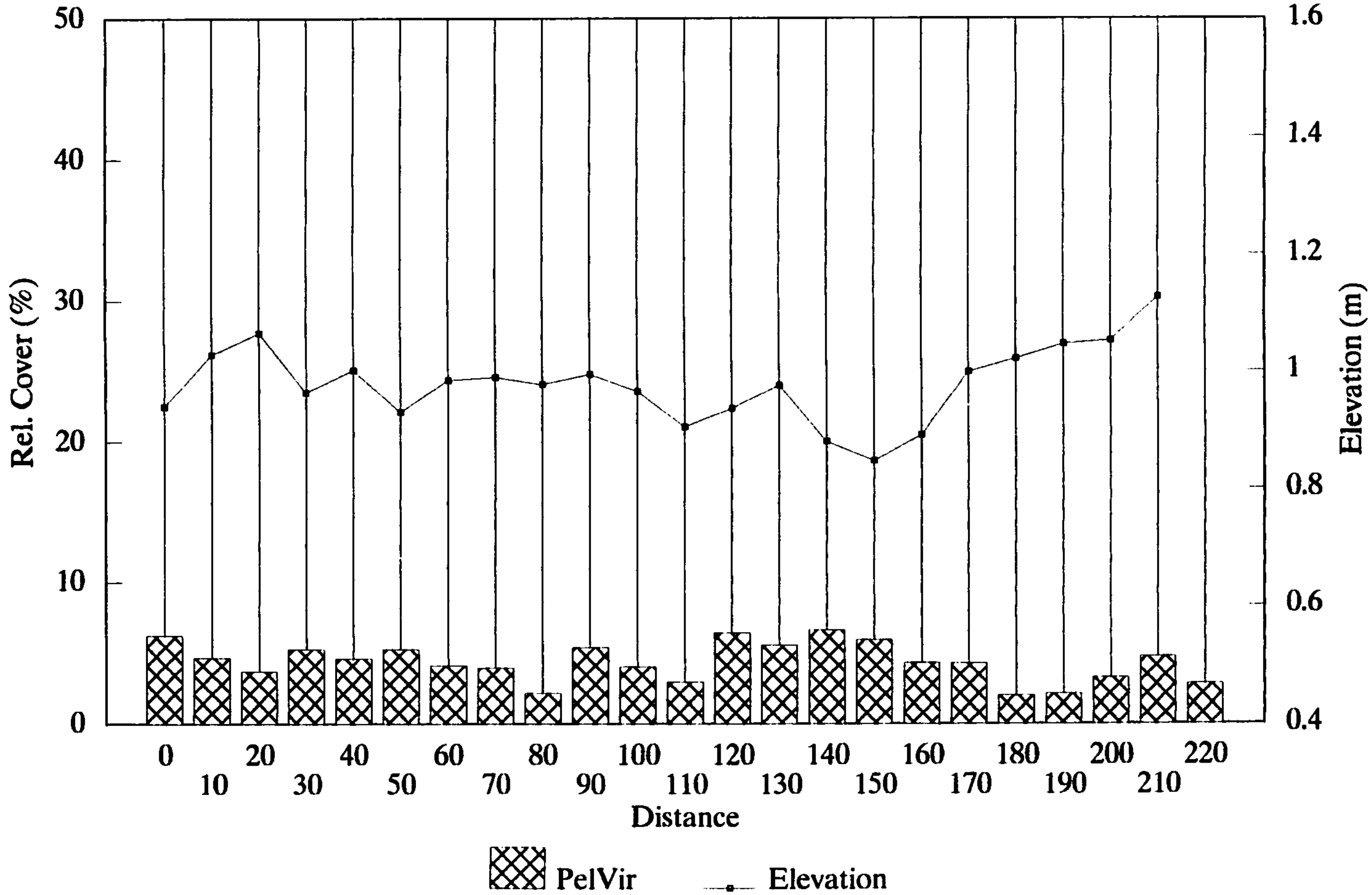


Note: Distance is measured in meters from the Pamunkey River.

Figure 11. Distribution of PelVir along transect 6.

DISTRIBUTION OF PelVir

TRANSECT 6

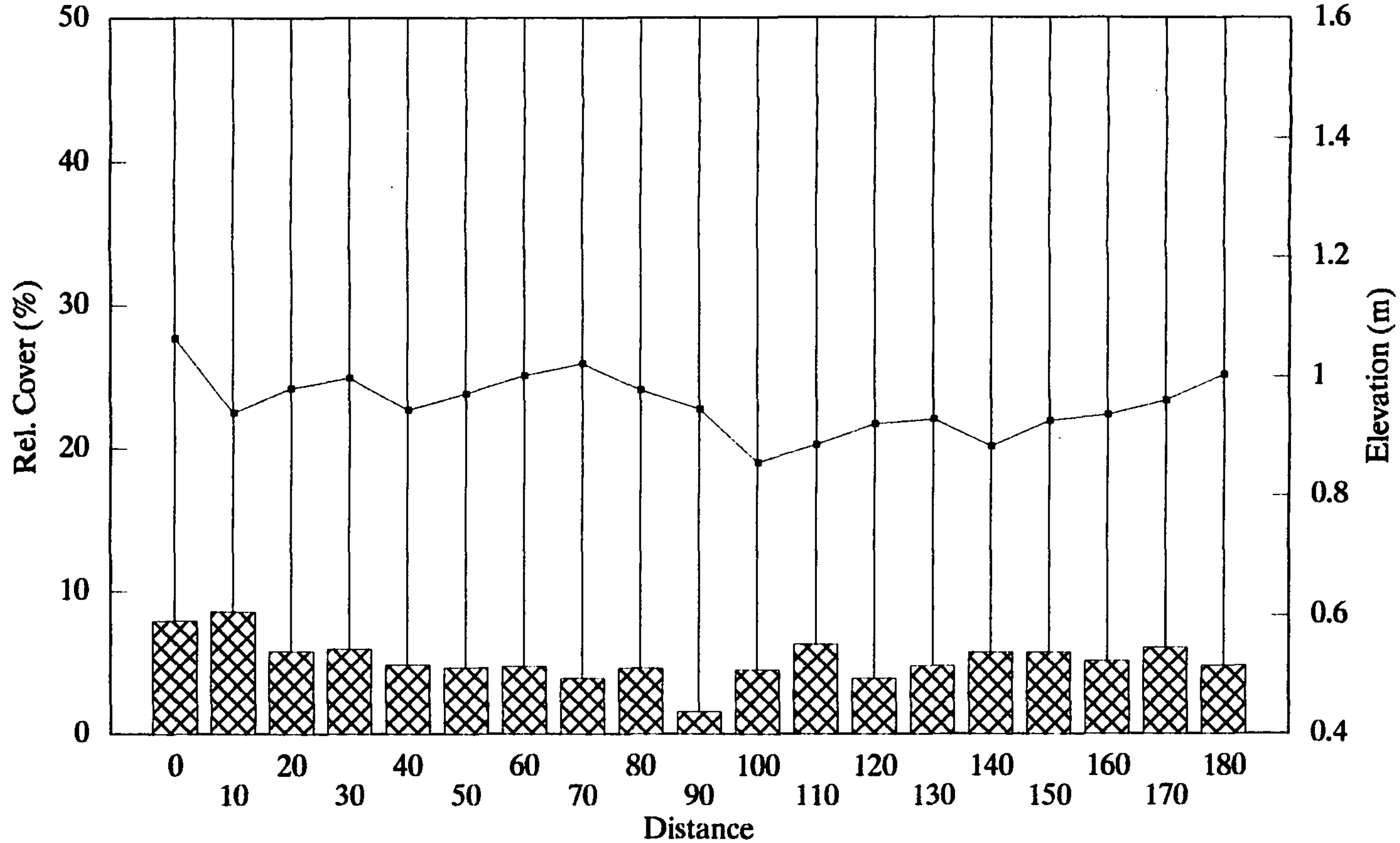


Note: Distance is measured in meters from the creek.

Figure 12. Distribution of PelVir along transect 7.

DISTRIBUTION OF PelVir

TRANSECT 7

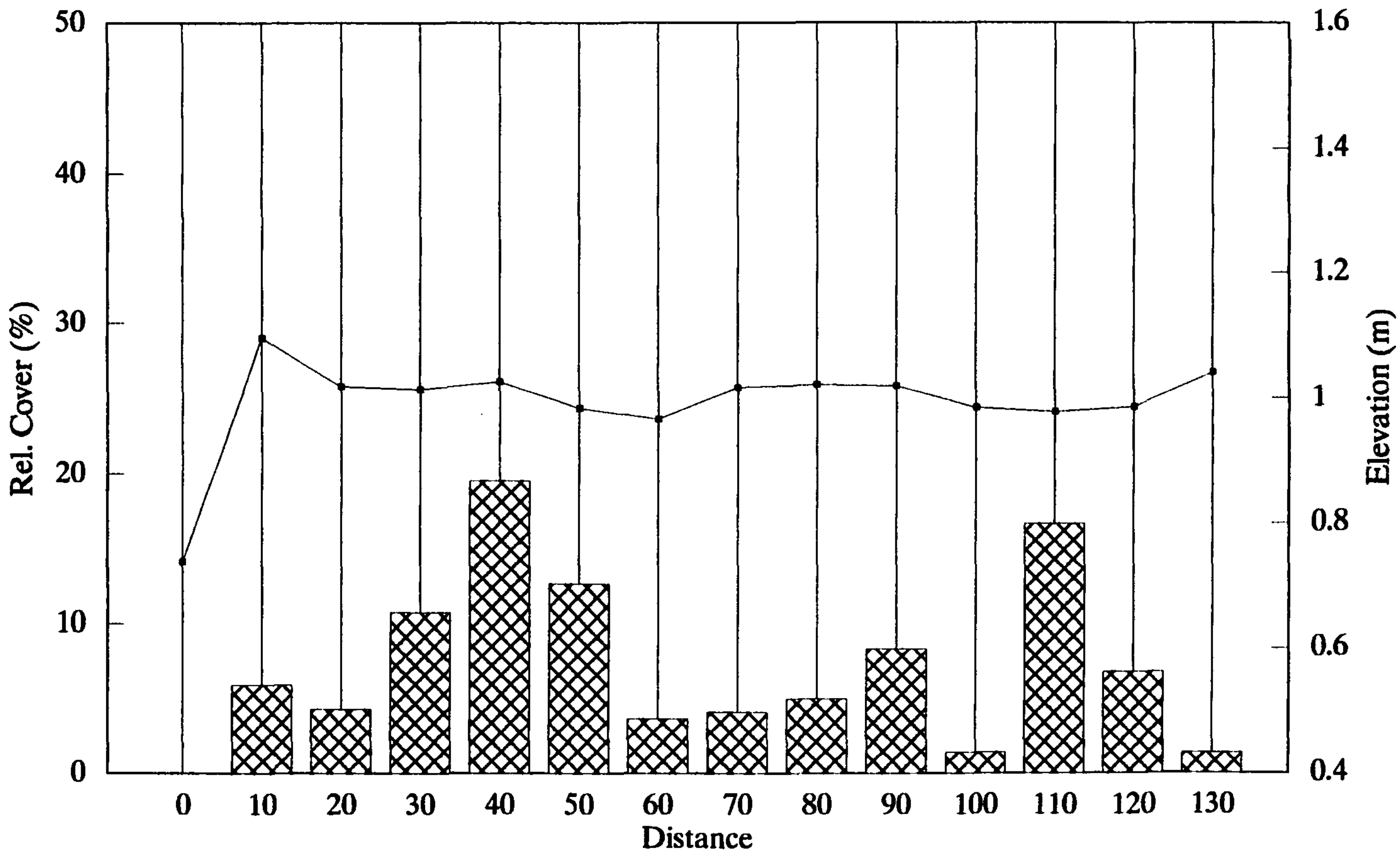


Note: Distance is measured in meters from the creek.

Figure 13. Distribution of LeeOry along transect 1.

DISTRIBUTION OF LeeOry

TRANSECT 1

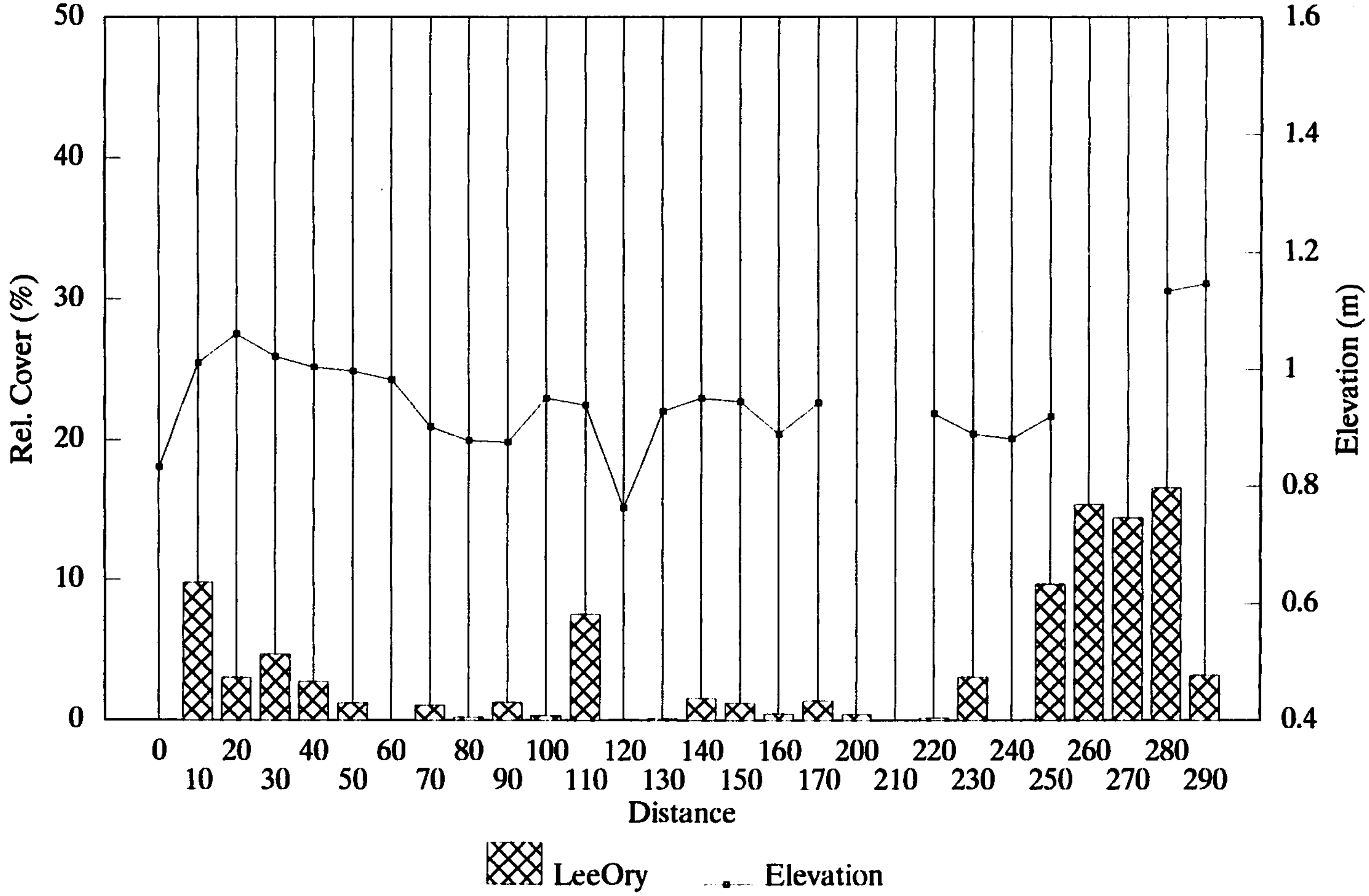


Note: Distance is measured in meters from the creek.

Figure 14. Distribution of LeeOry along transect 2.

DISTRIBUTION OF LeeOry

TRANSECT 2

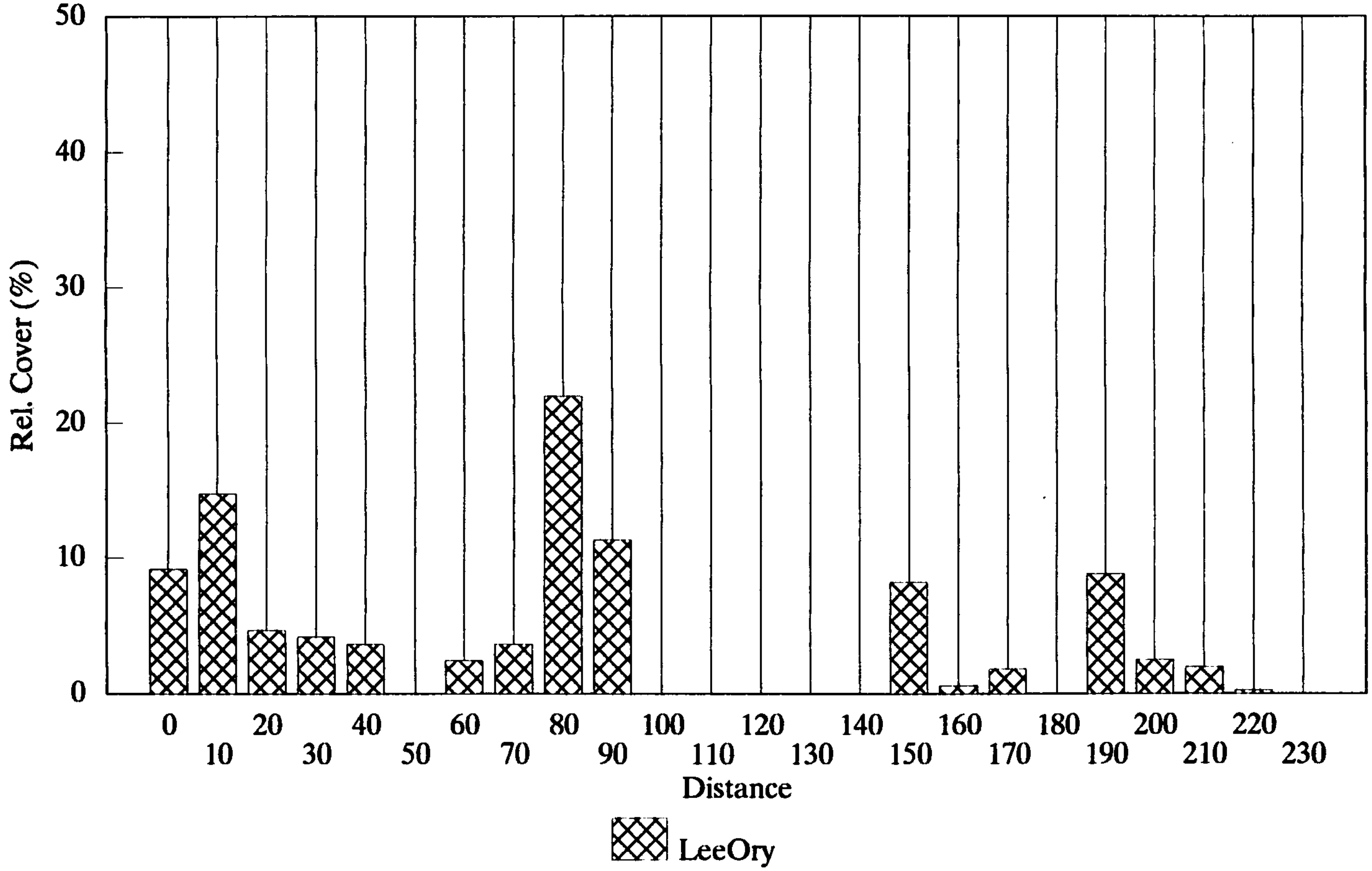


Note: Distance is measured in meters from the creek.

Figure 15. Distribution of LeeOry along transect 3.

DISTRIBUTION OF LeeOry

TRANSECT 3

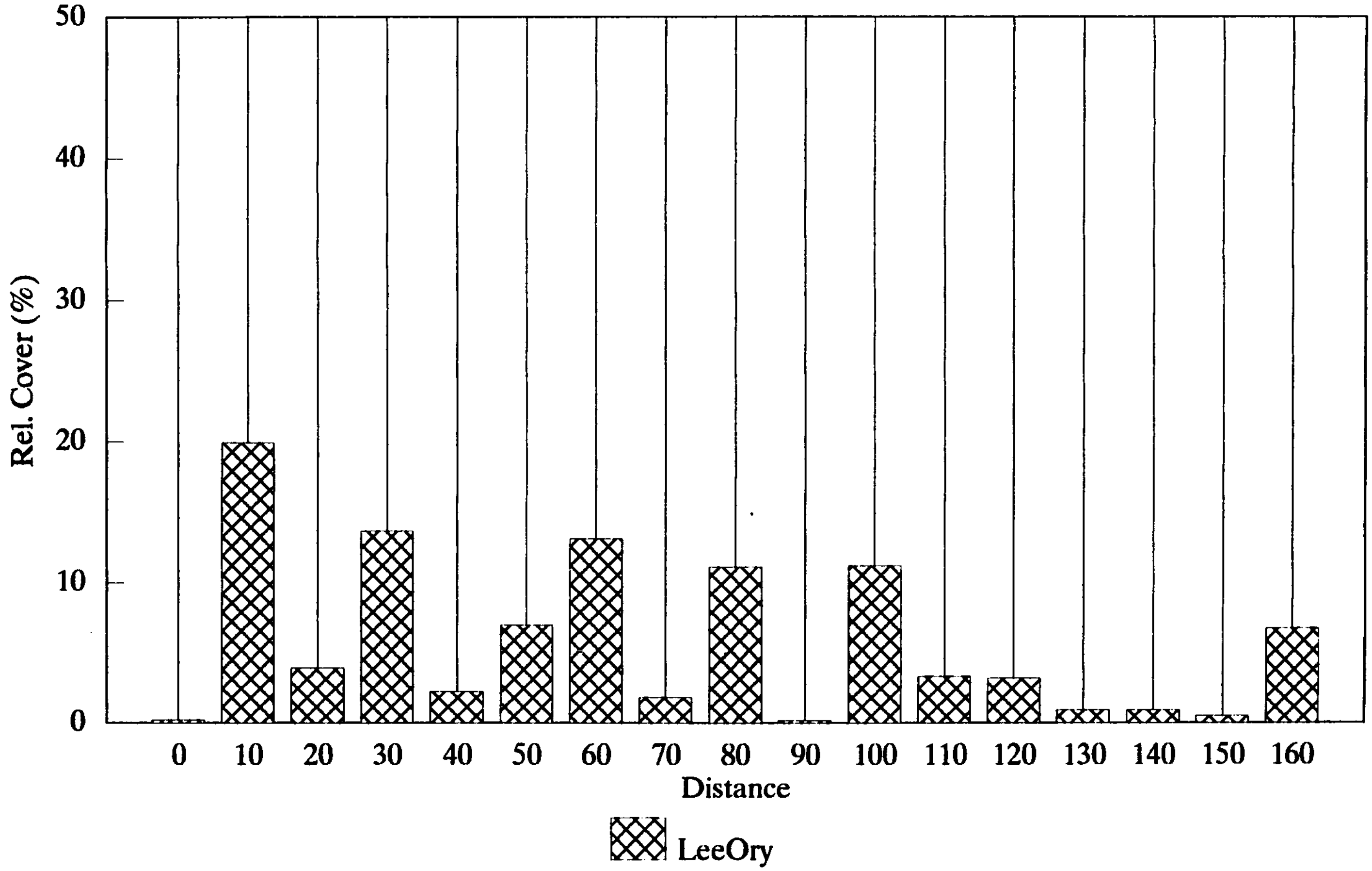


Note:1.Distance is measured in meters from the creek.
2. No elevation data available for this transect.

Figure 16. Distribution of LeeOry along transect 4.

DISTRIBUTION OF LeeOry

TRANSECT 4

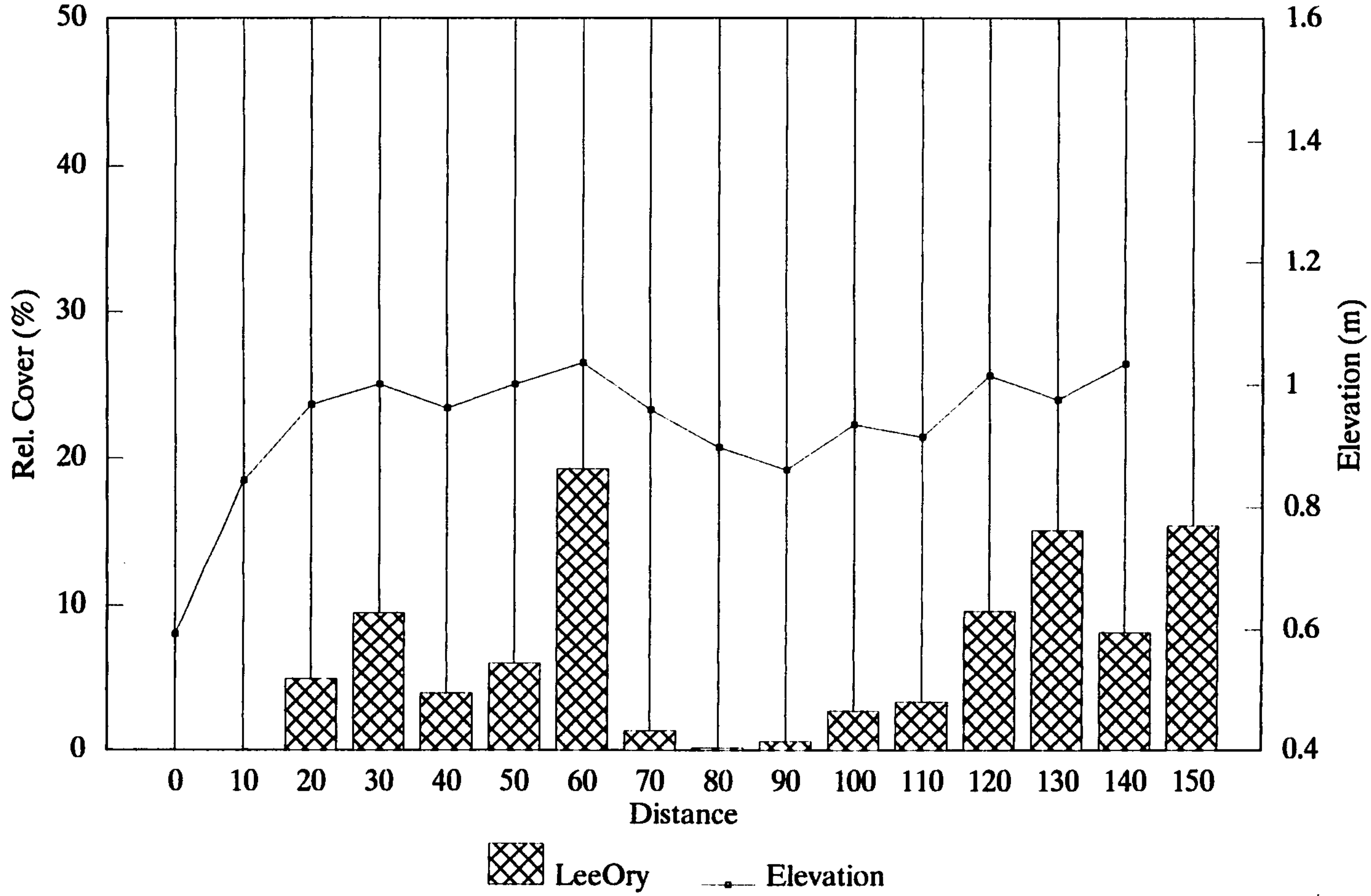


Note:1.Distance is measured in meters from the creek.
2.No elevation data available for this transect.

Figure 17. Distribution of LeeOry along transect 5.

DISTRIBUTION OF LeeOry

TRANSECT 5

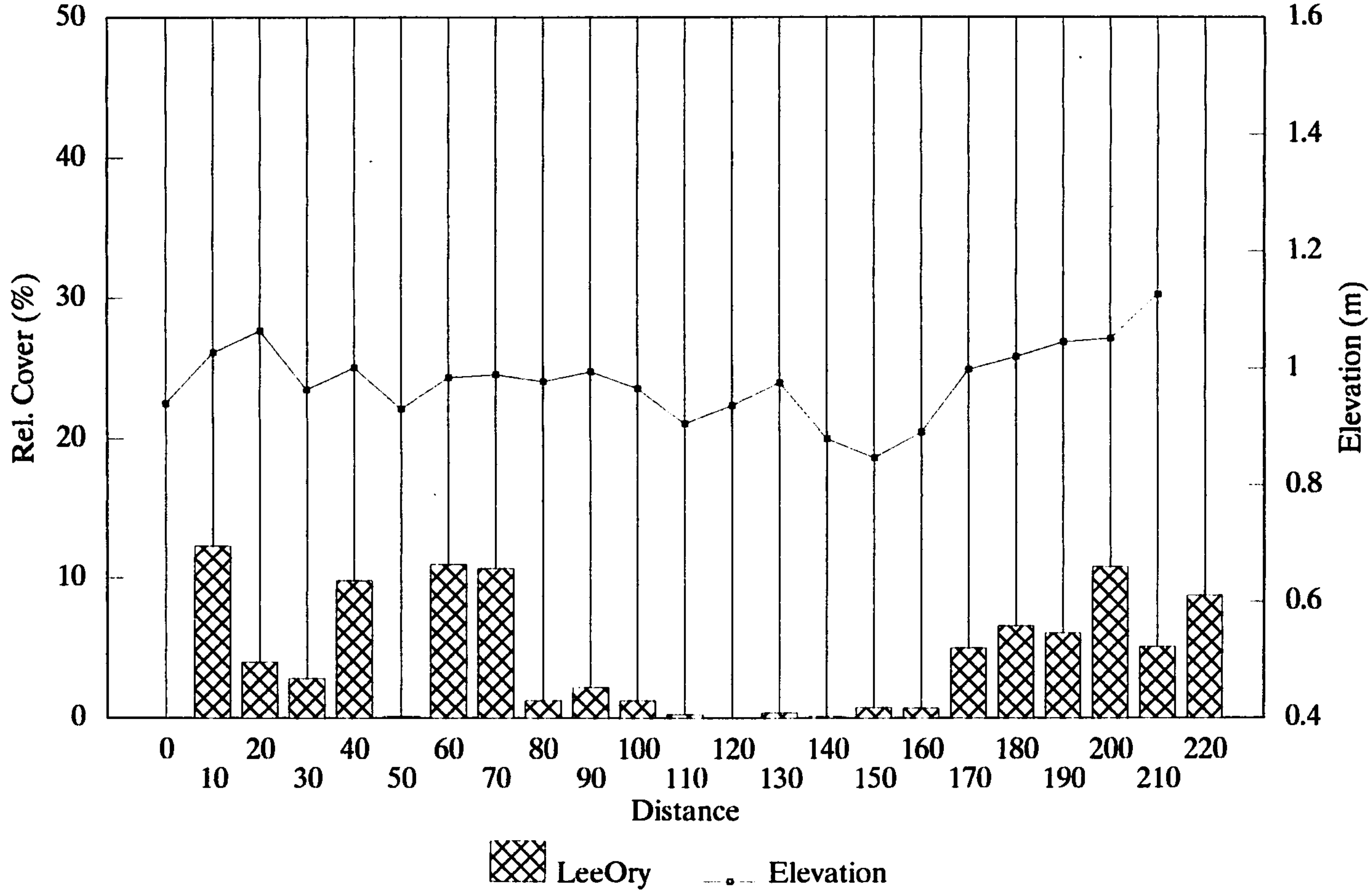


Note: Distance is measured in meters from the Pamunkey River.

Figure 18. Distribution of LeeOry along transect 6.

DISTRIBUTION OF LeeOry

TRANSECT 6

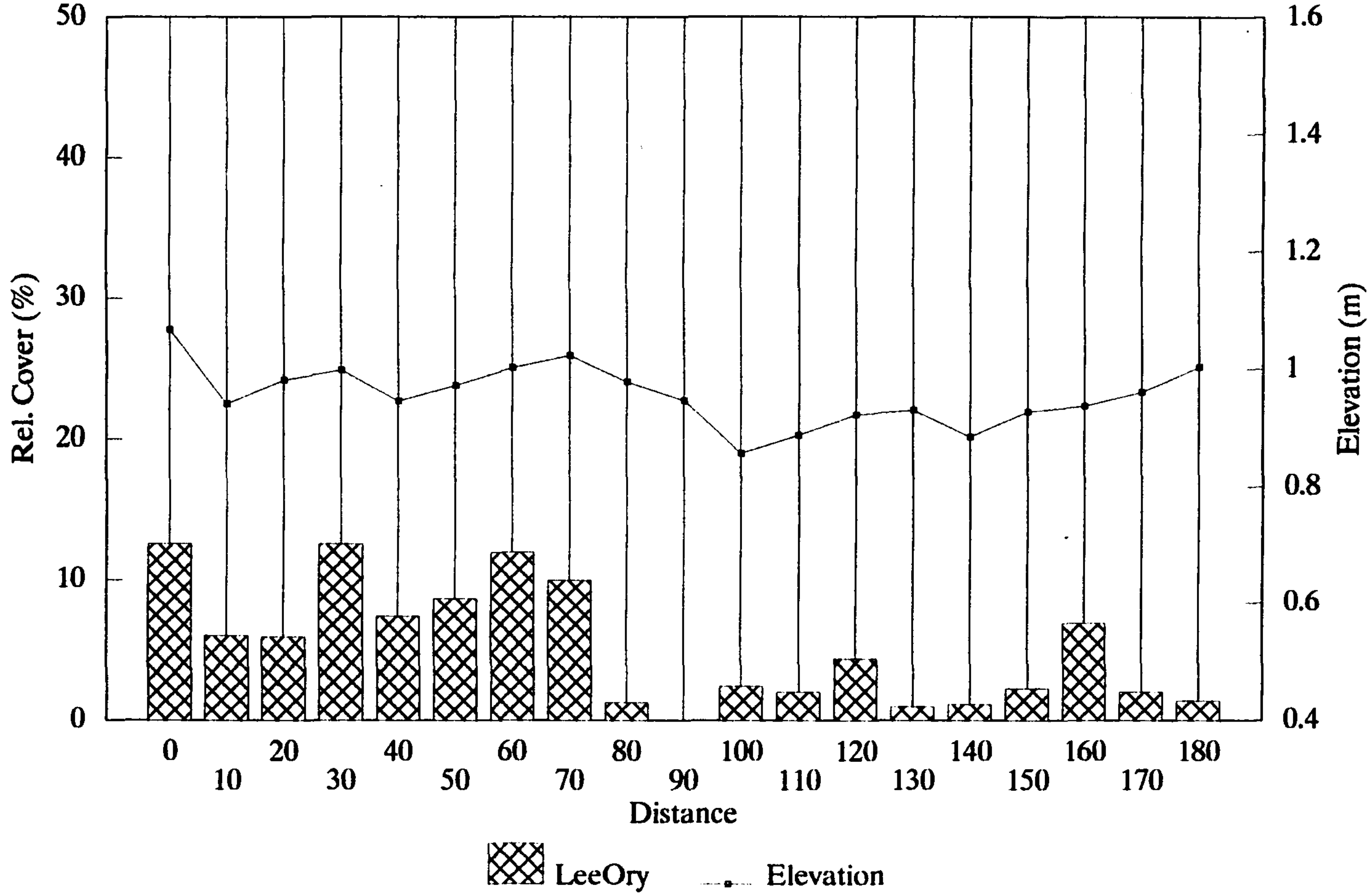


Note: Distance is measured in meters from the creek.

Figure 19. Distribution of LeeOry along transect 7.

DISTRIBUTION OF LeeOry

TRANSECT 7

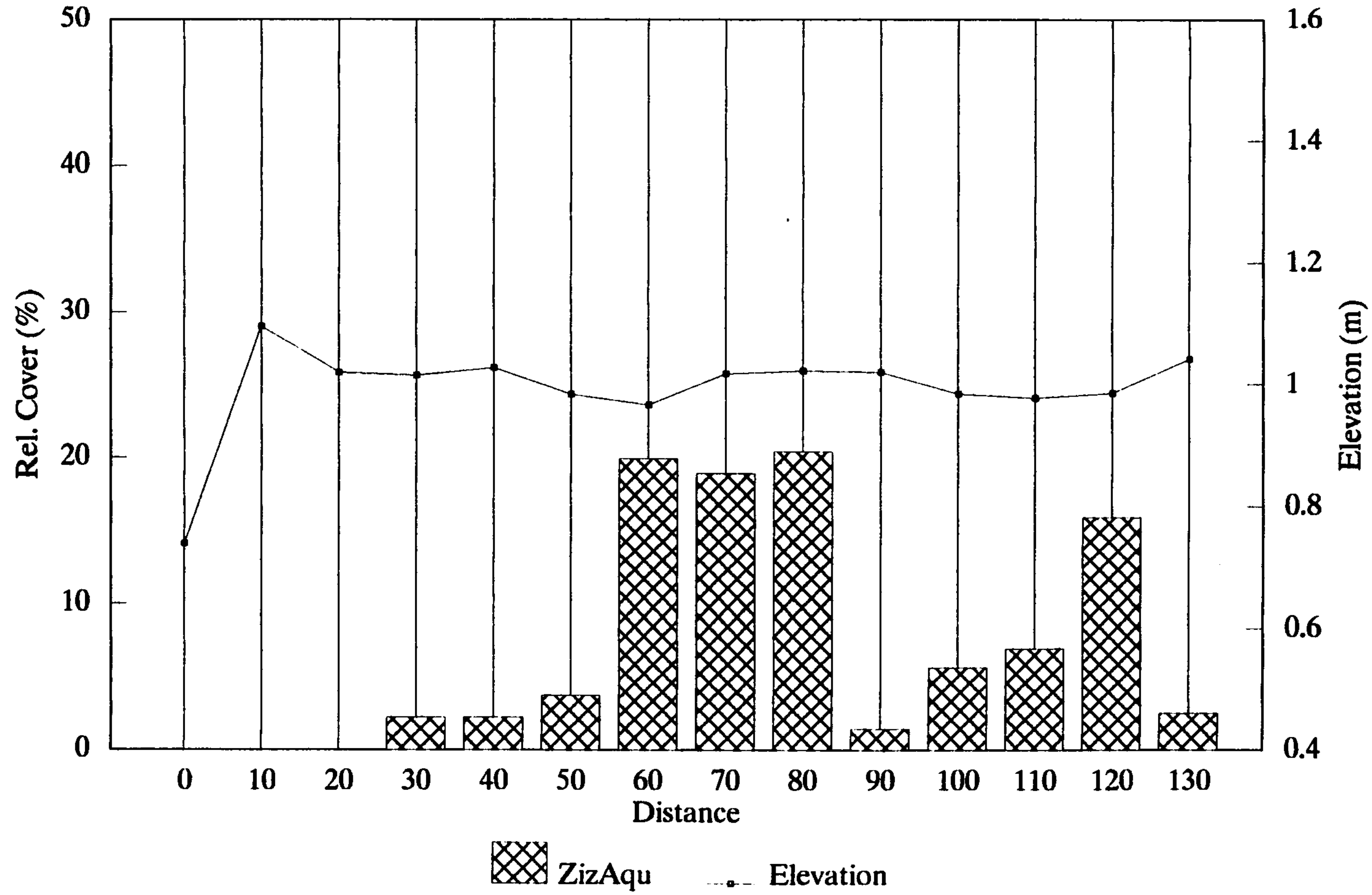


Note: Distance is measured in meters from the creek.

Figure 20. Distribution of ZizAqu along transect 1.

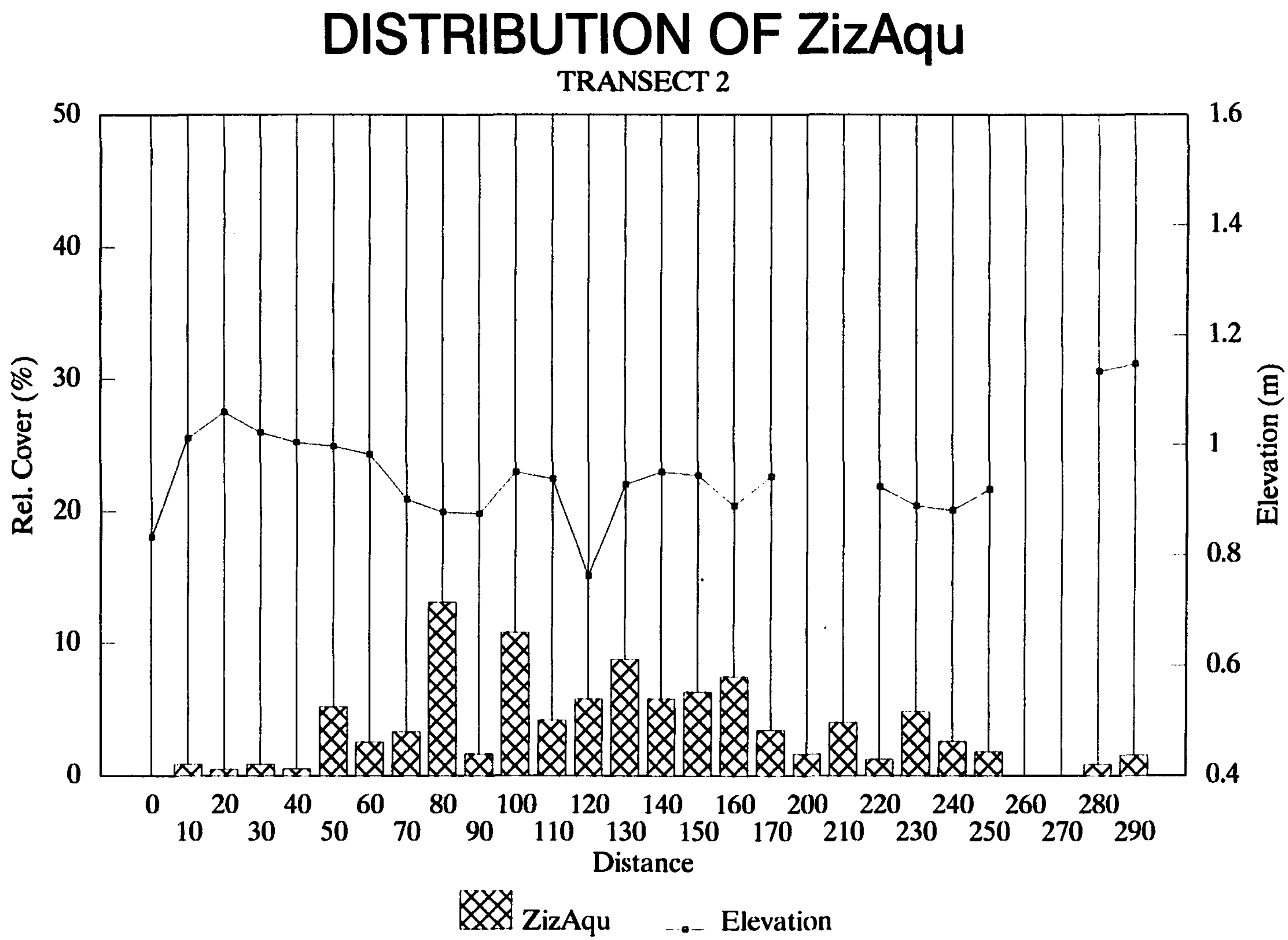
DISTRIBUTION OF ZizAqu

TRANSECT 1



Note: Distance is measured in meters from the creek.

Figure 21. Distribution of ZizAqu along transect 2.

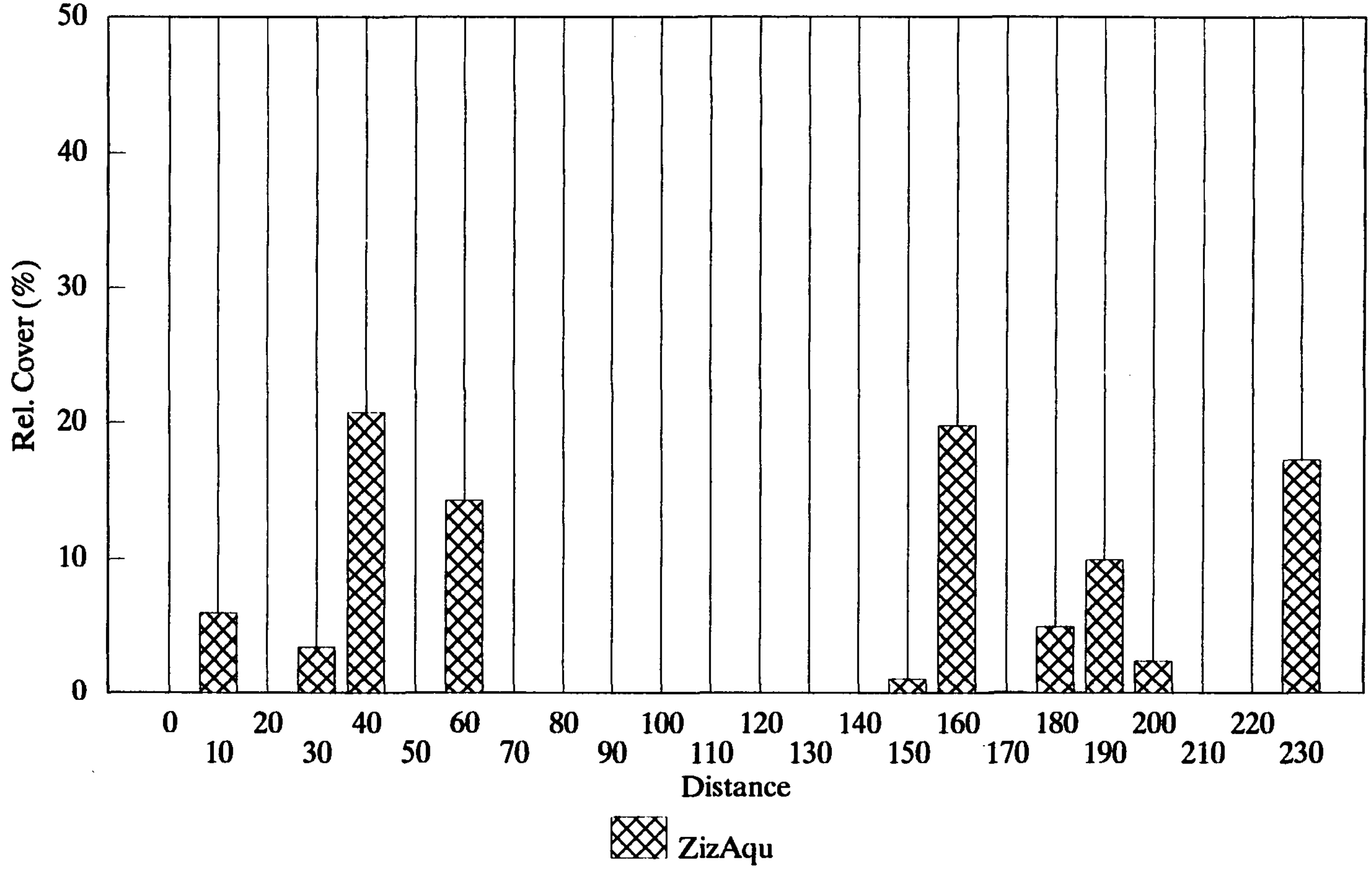


Note: Distance is measured in meters from the creek.

Figure 22. Distribution of ZizAqu along transect 3.

DISTRIBUTION OF ZizAqu

TRANSECT 3

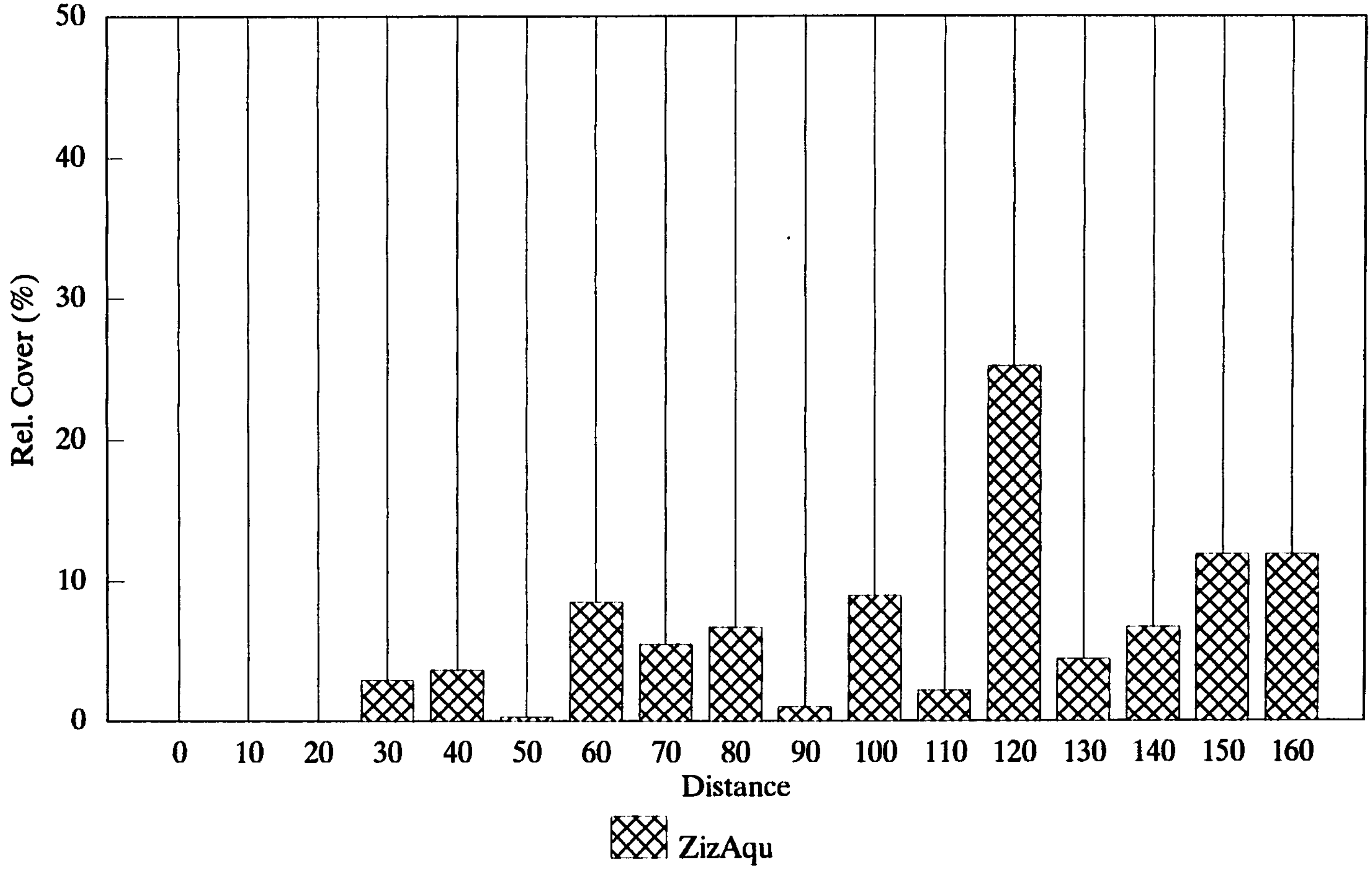


Note: 1. Distance is measured in meters from the creek.
2. No elevation data available for this transect.

Figure 23. Distribution of ZizAqu along transect 4.

DISTRIBUTION OF ZizAqu

TRANSECT 4

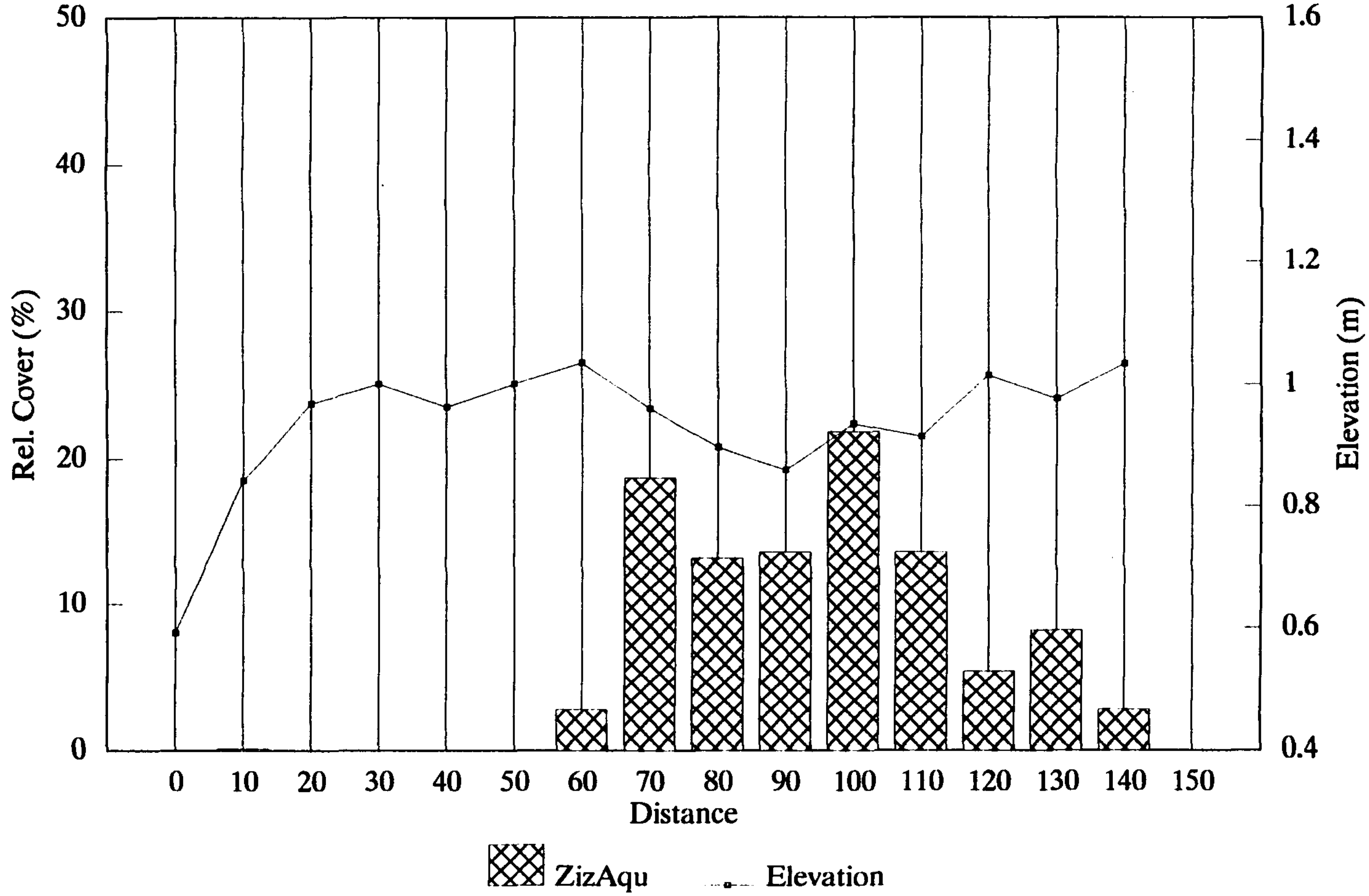


Note:1.Distance is measured in meters from the creek.
2.No elevation data available for this transect.

Figure 24. Distribution of ZizAqu along transect 5.

DISTRIBUTION OF ZizAqu

TRANSECT 5

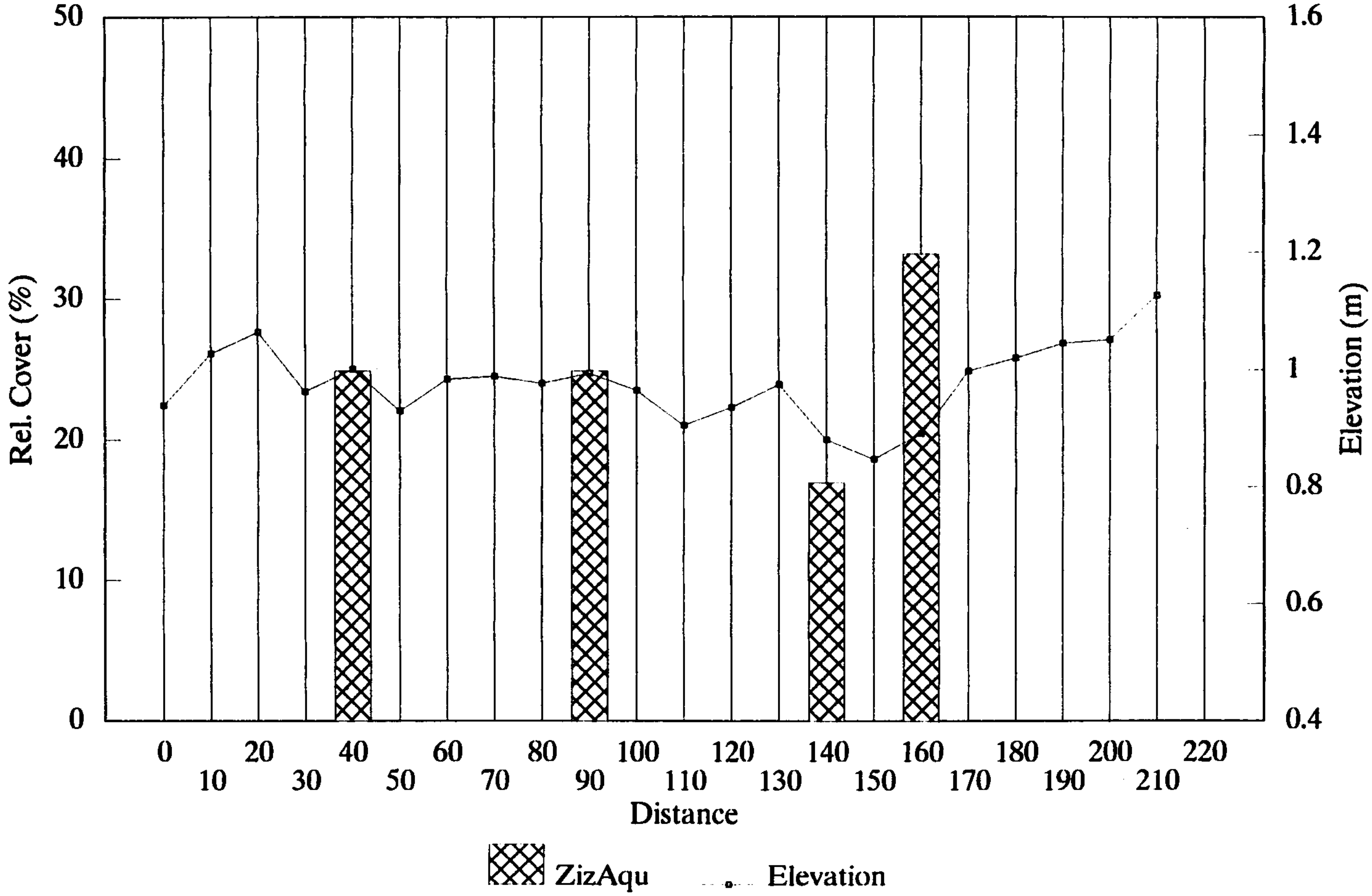


Note: Distance is measured in meters from the Pamunkey River.

Figure 25. Distribution of ZizAqu along transect 6.

DISTRIBUTION OF ZizAqu

TRANSECT 6

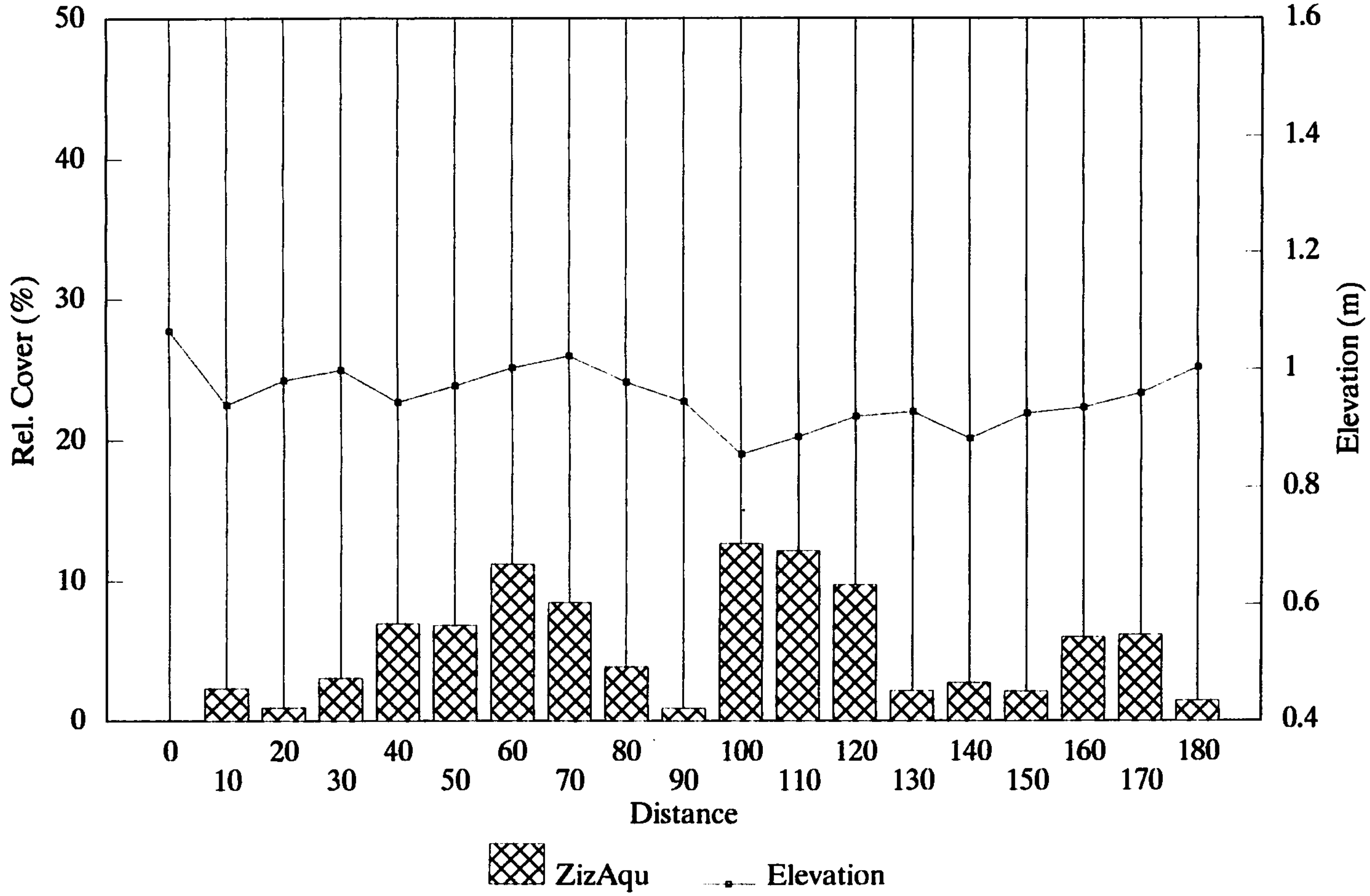


Note: Distance is measured in meters from the creek.

Figure 26. Distribution of ZizAqu along transect 7.

DISTRIBUTION OF ZizAqu

TRANSECT 7

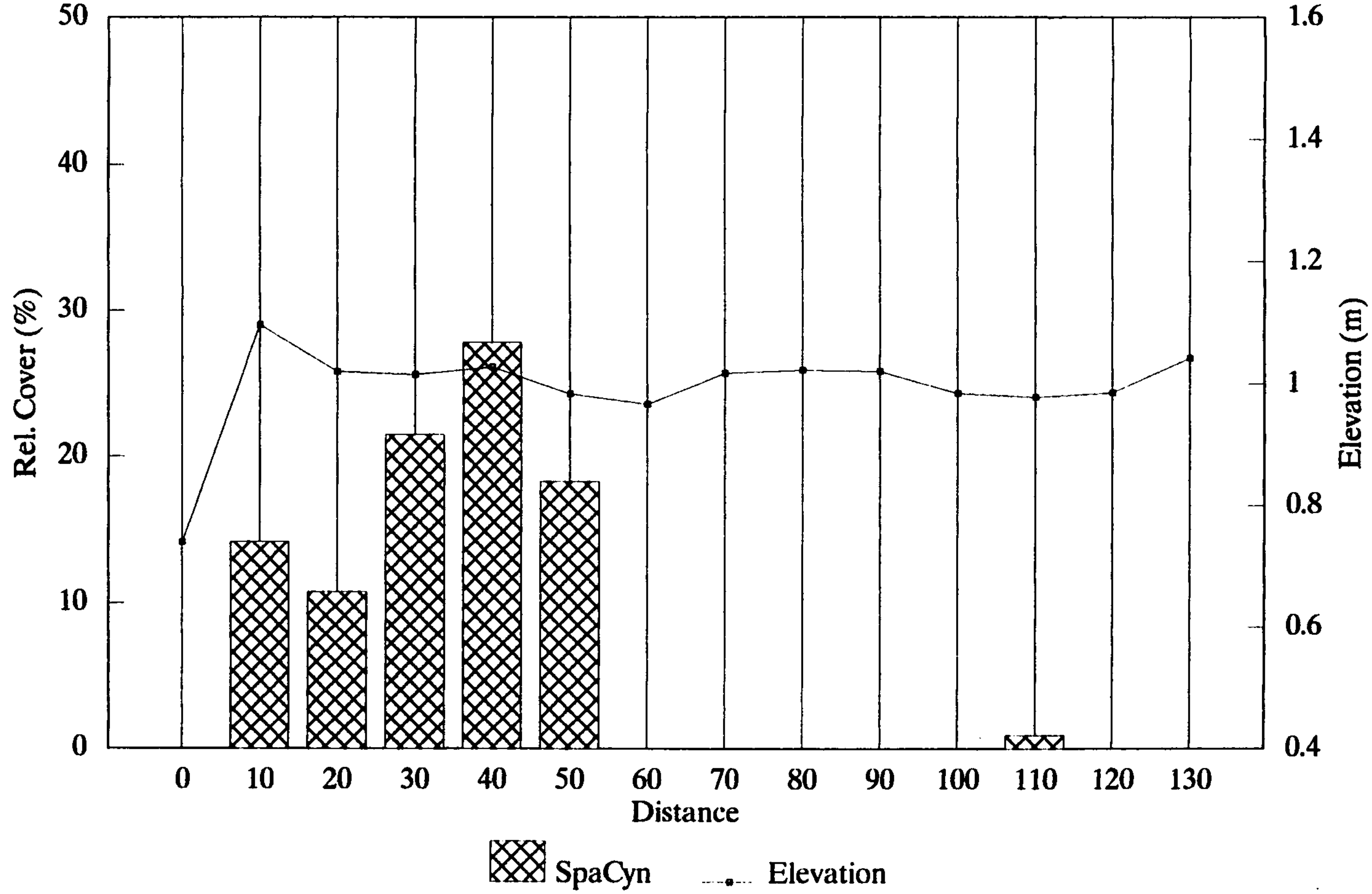


Note: Distance is measured in meters from the creek.

Figure 27. Distribution of SpaCyn along transect 1.

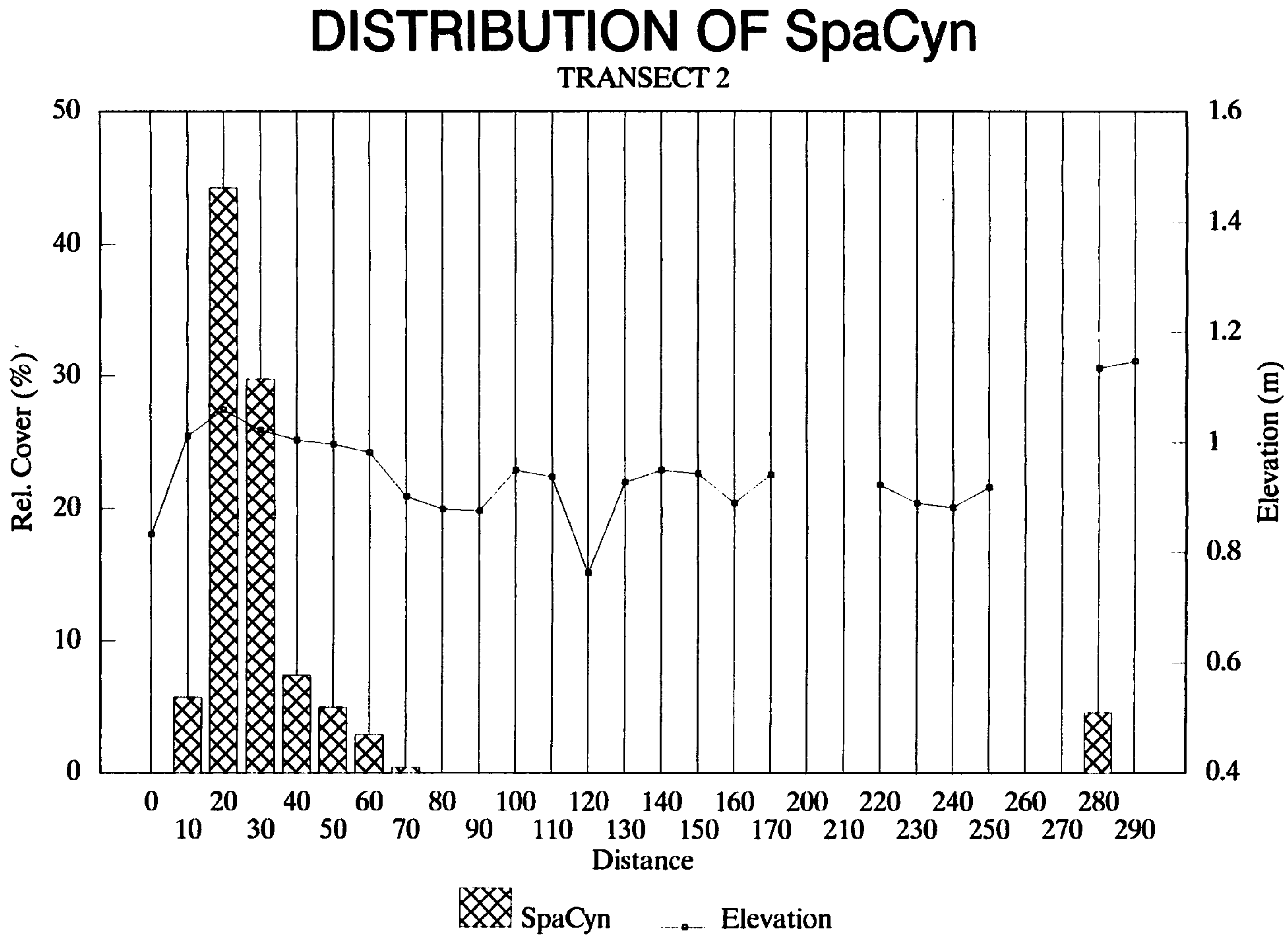
DISTRIBUTION OF SpaCyn

TRANSECT 1



Note: Distance is measured in meters from the creek.

Figure 28. Distribution of SpaCyn along transect 2.

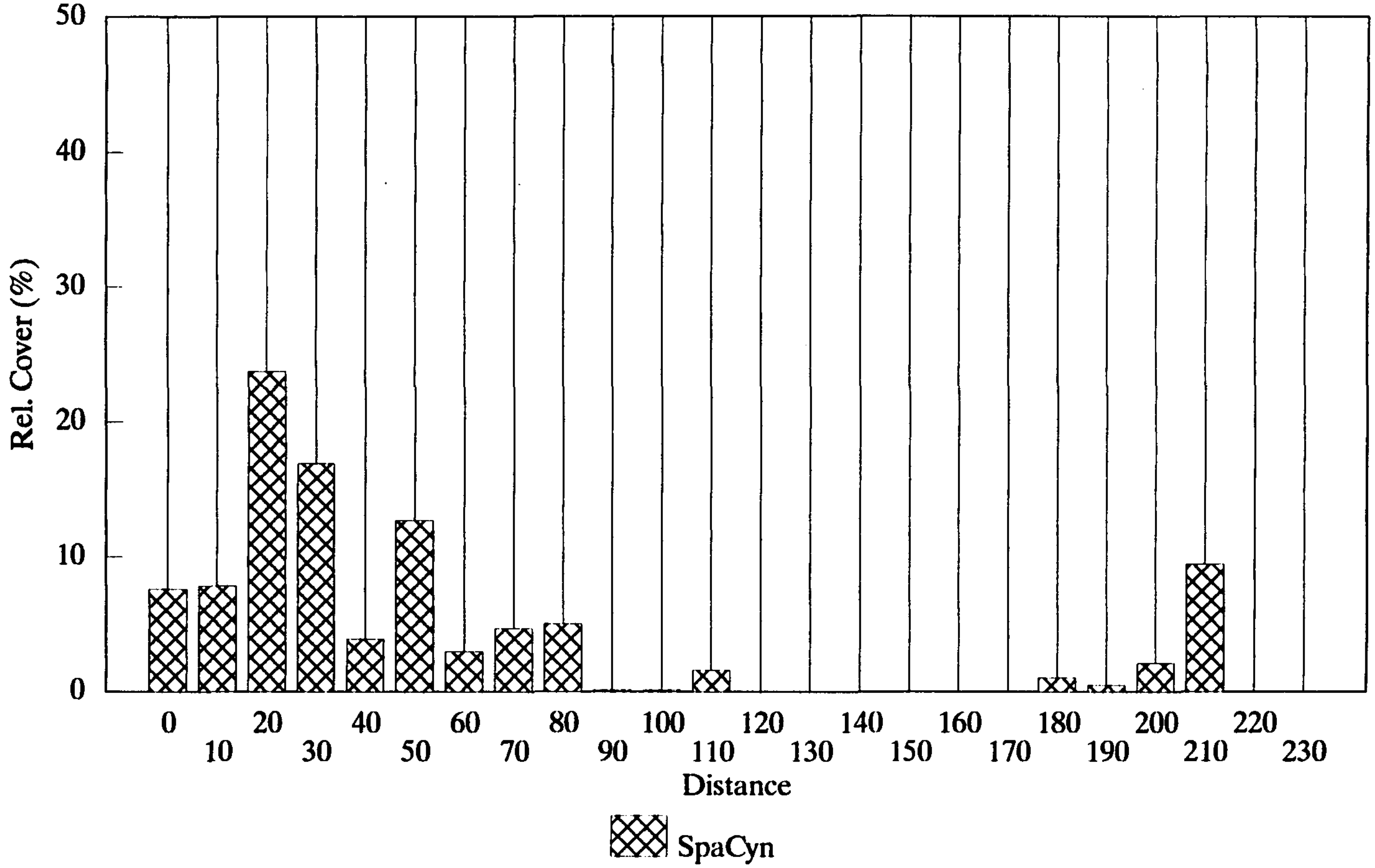


Note: Distance is measured in meters from the creek.

Figure 29. Distribution of SpaCyn along transect 3.

DISTRIBUTION OF SpaCyn

TRANSECT 3

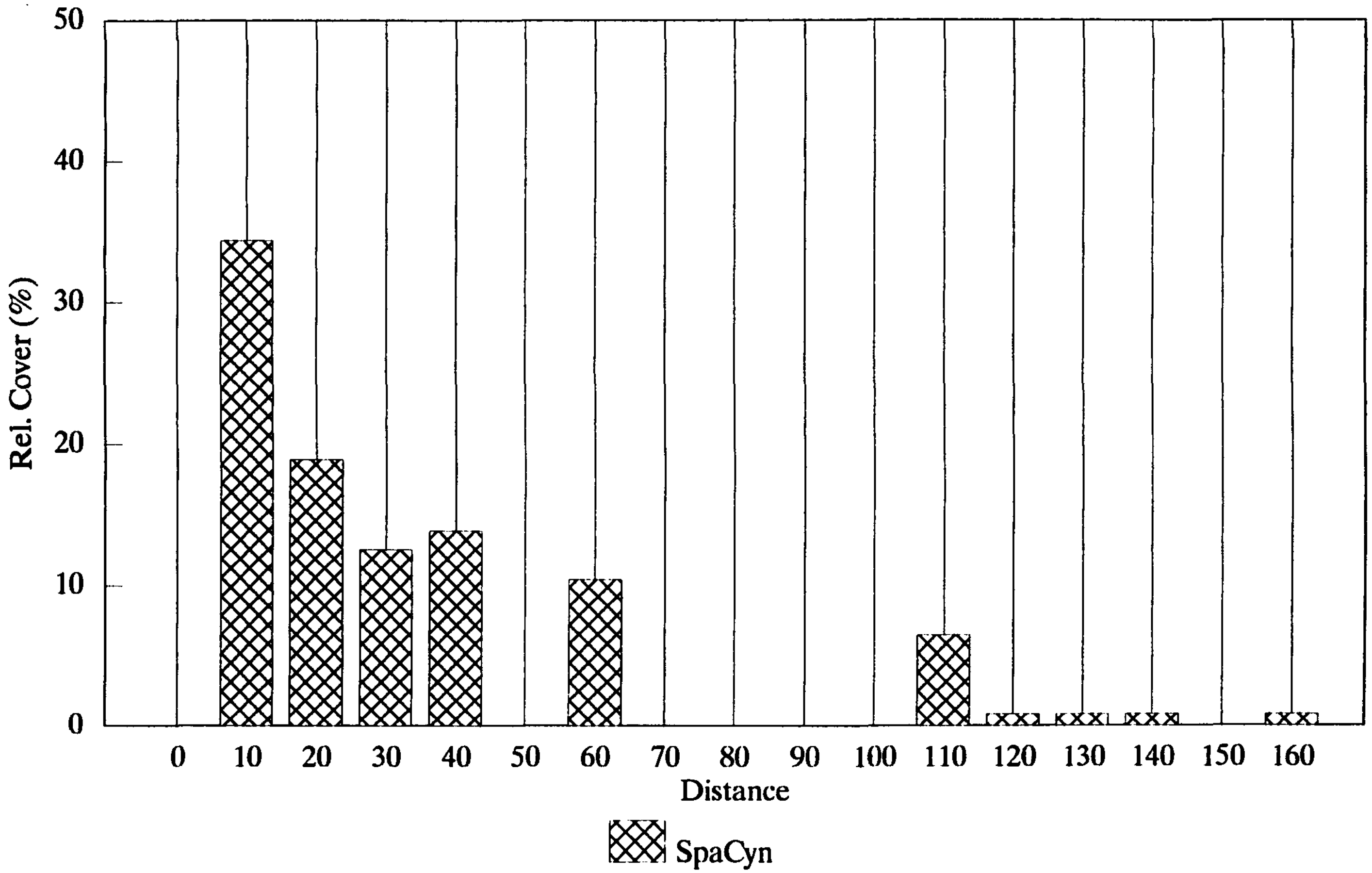


Note: 1. Distance is measured in meters from the creek.
2. No elevation data available for this transect.

Figure 30. Distribution of SpaCyn along transect 4.

DISTRIBUTION OF SpaCyn

TRANSECT 4

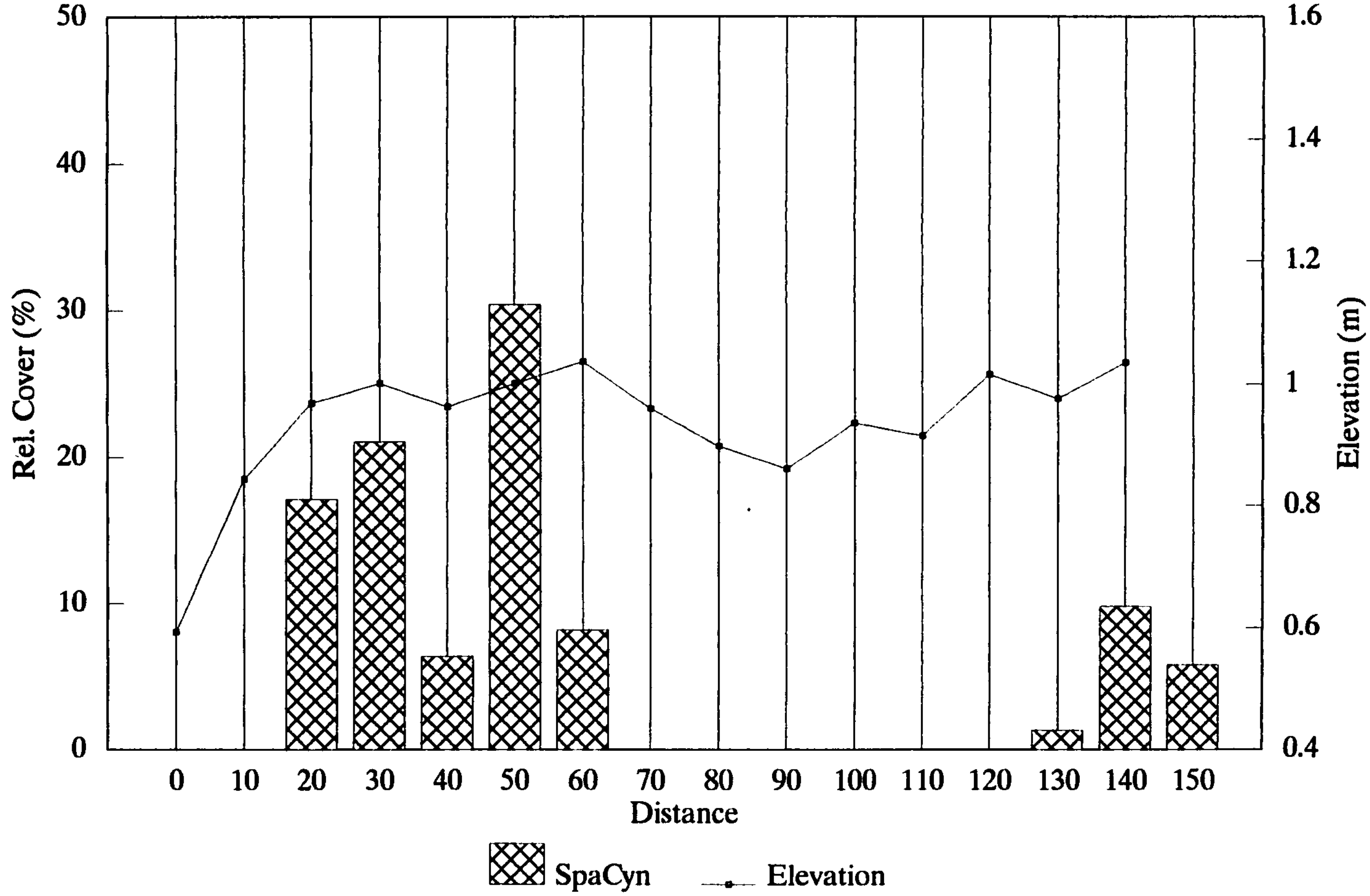


Note:1.Distance is measured in meters from the creek.
2.No elevation data available for this transect.

Figure 31. Distribution of SpaCyn along transect 5.

DISTRIBUTION OF SpaCyn

TRANSECT 5

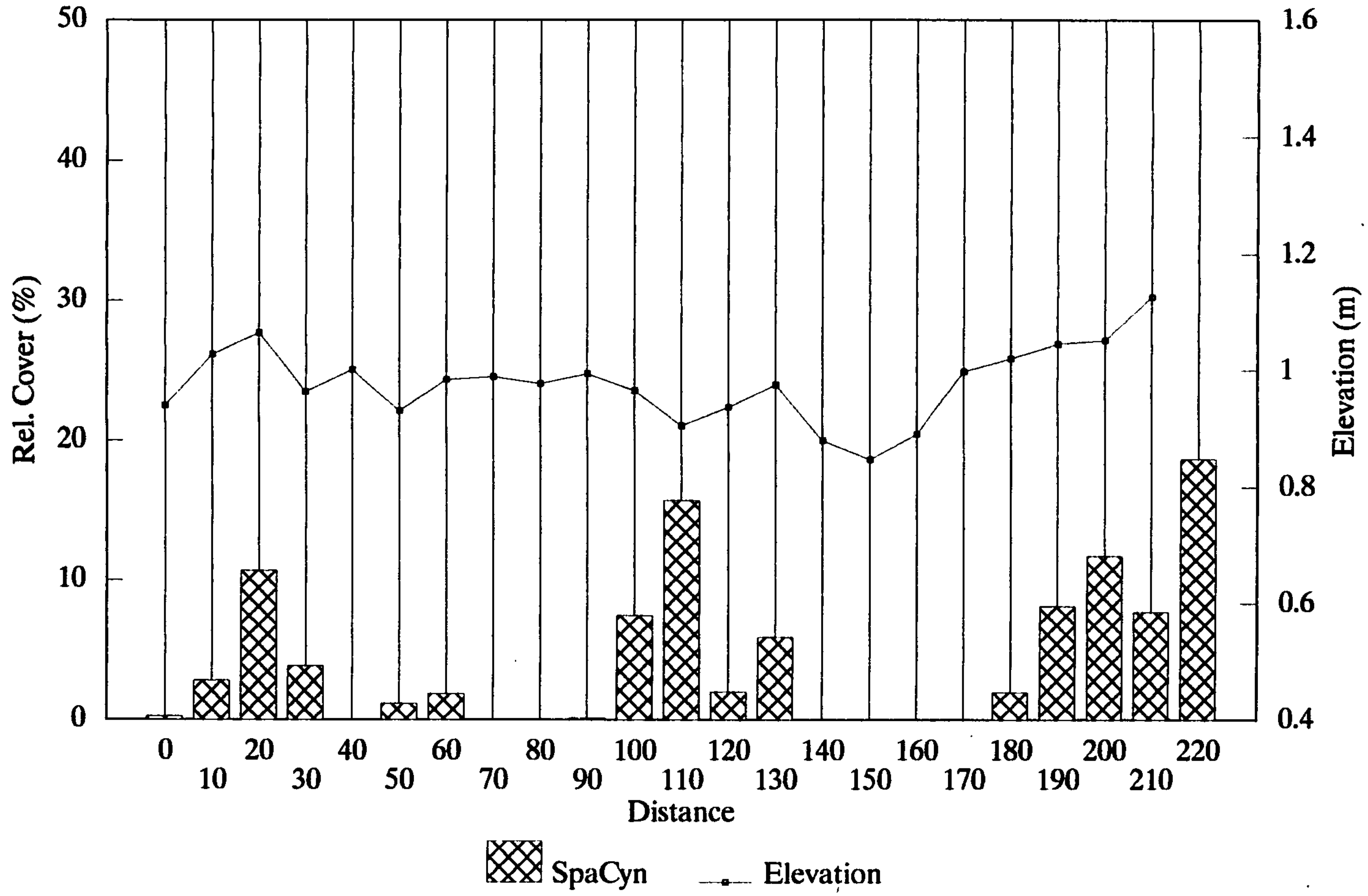


Note: Distance is measured in meters from the Pamunkey River.

Figure 32. Distribution of SpaCyn along transect 6.

DISTRIBUTION OF SpaCyn

TRANSECT 6

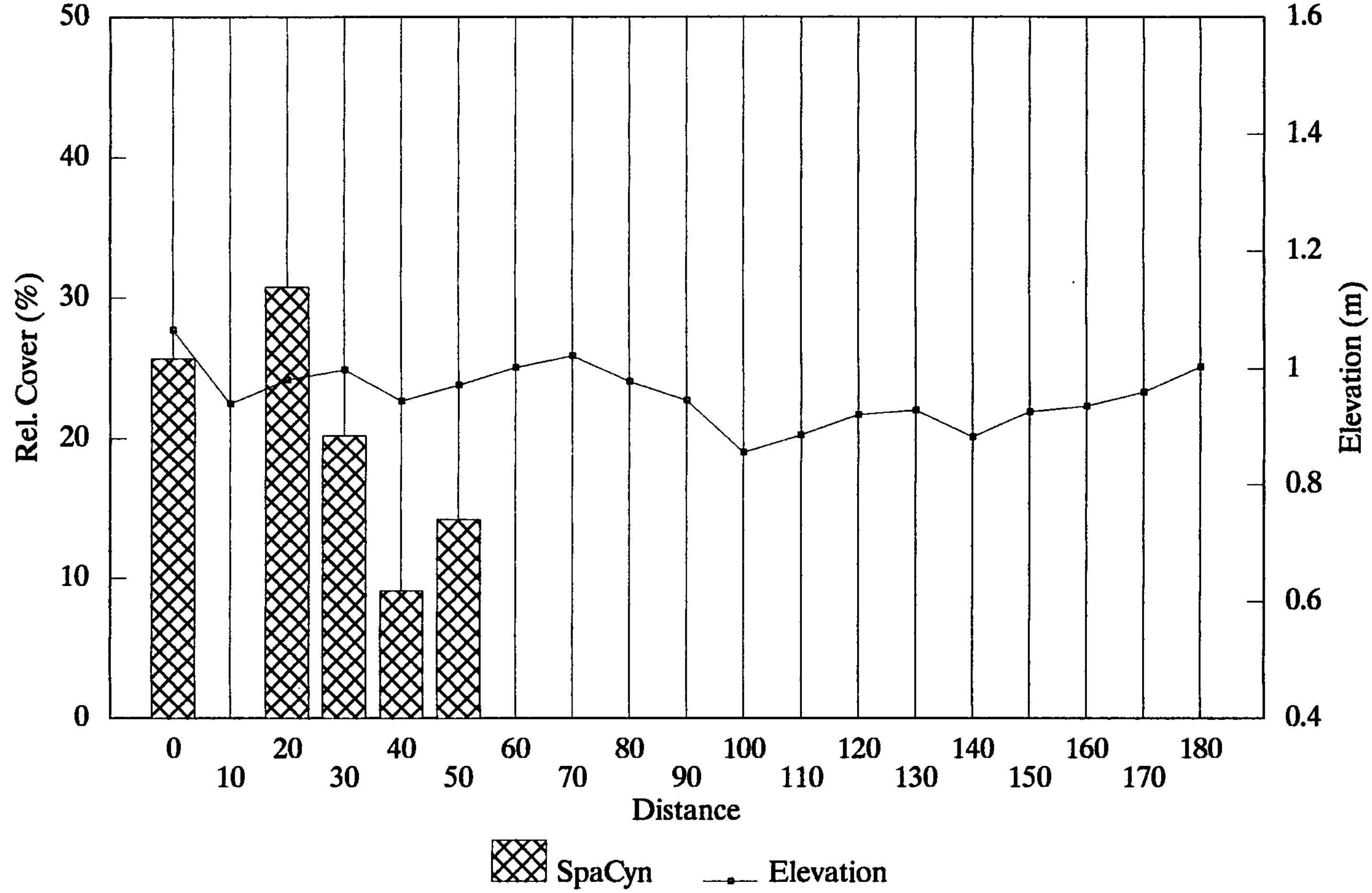


Note: Distance is measured in meters from the creek.

Figure 33. Distribution of SpaCyn along transect 7.

DISTRIBUTION OF SpaCyn

TRANSECT 7

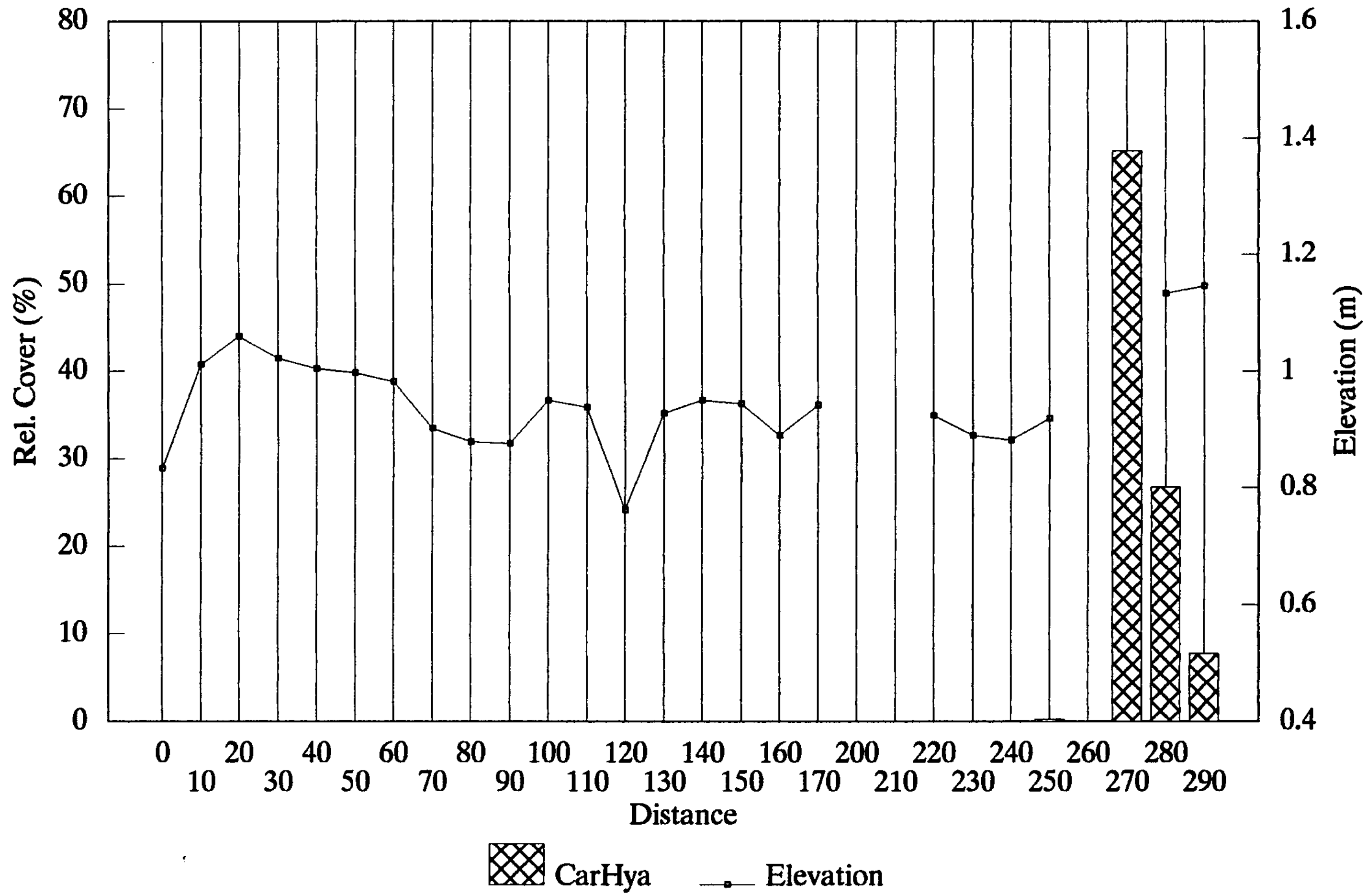


Note: Distance is measured in meters from the creek.

Figure 34. Distribution of CarHya along transect 2.

DISTRIBUTION OF CarHya

TRANSECT 2

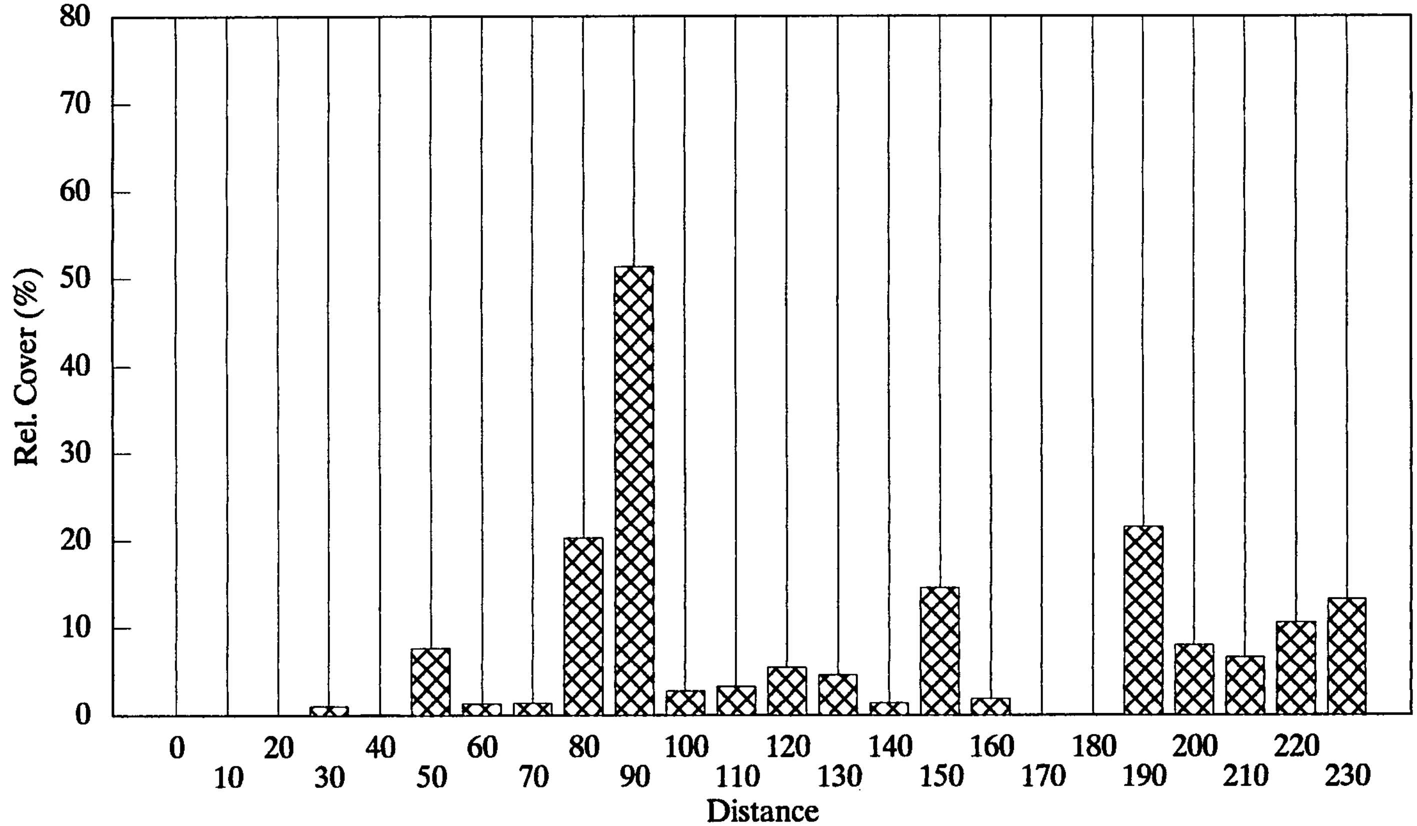


Note: Distance is measured in meters from the creek.

Figure 35. Distribution of CarHya along transect 3.

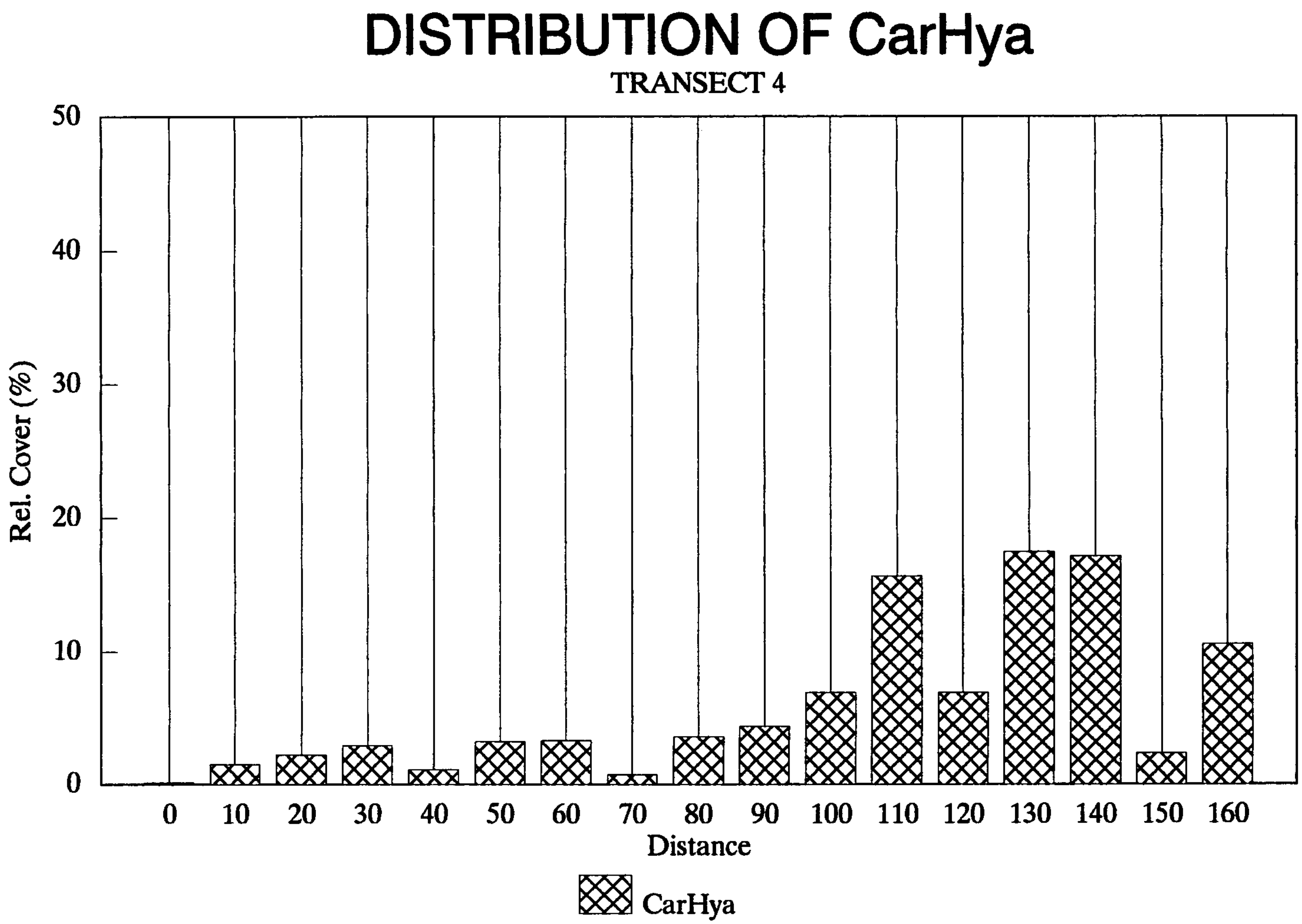
DISTRIBUTION OF CarHya

TRANSECT 3



Note: 1. Distance is measured in meters from the creek.
2. No elevation data available for this transect.

Figure 36. Distribution of CarHya along transect 4.

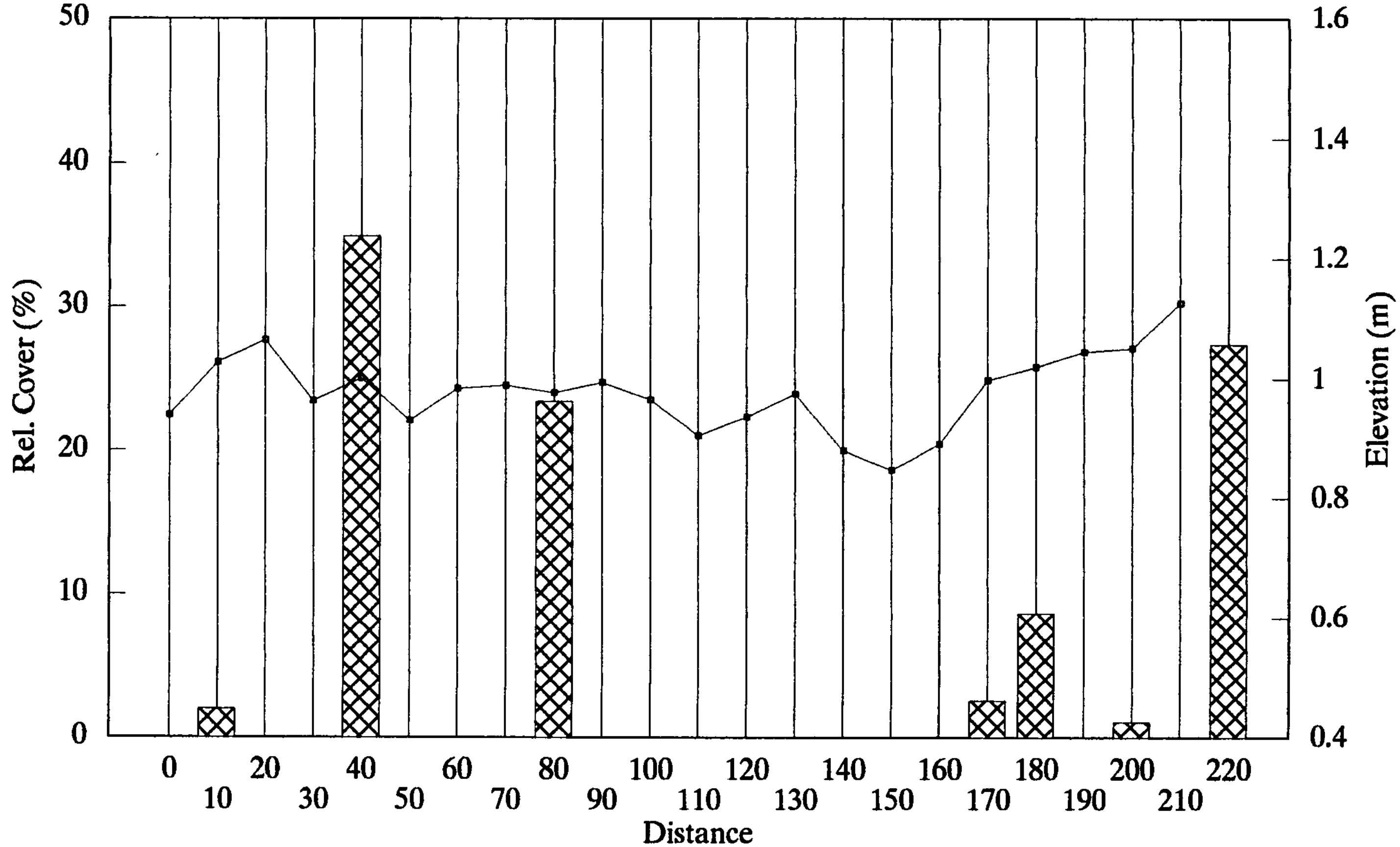


Note:1.Distance is measured in meters from the creek.
2.No elevation data available for this transect.

Figure 37. Distribution of CarHya along transect 6.

DISTRIBUTION OF CarHya

TRANSECT 6

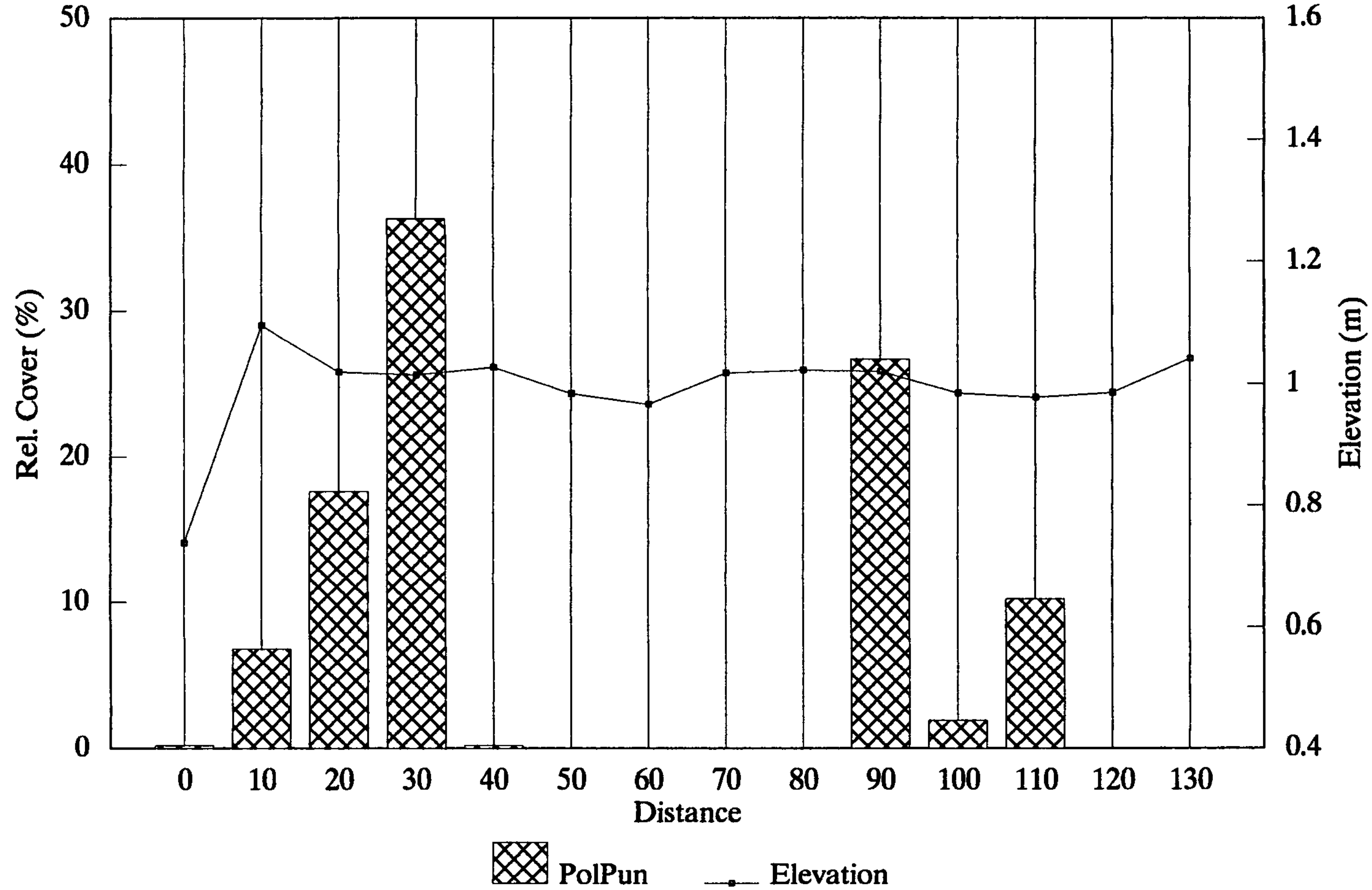


Note: Distance is measured in meters from the creek.

Figure 38. Distribution of PolPun along transect 1.

DISTRIBUTION OF PolPun

TRANSECT 1

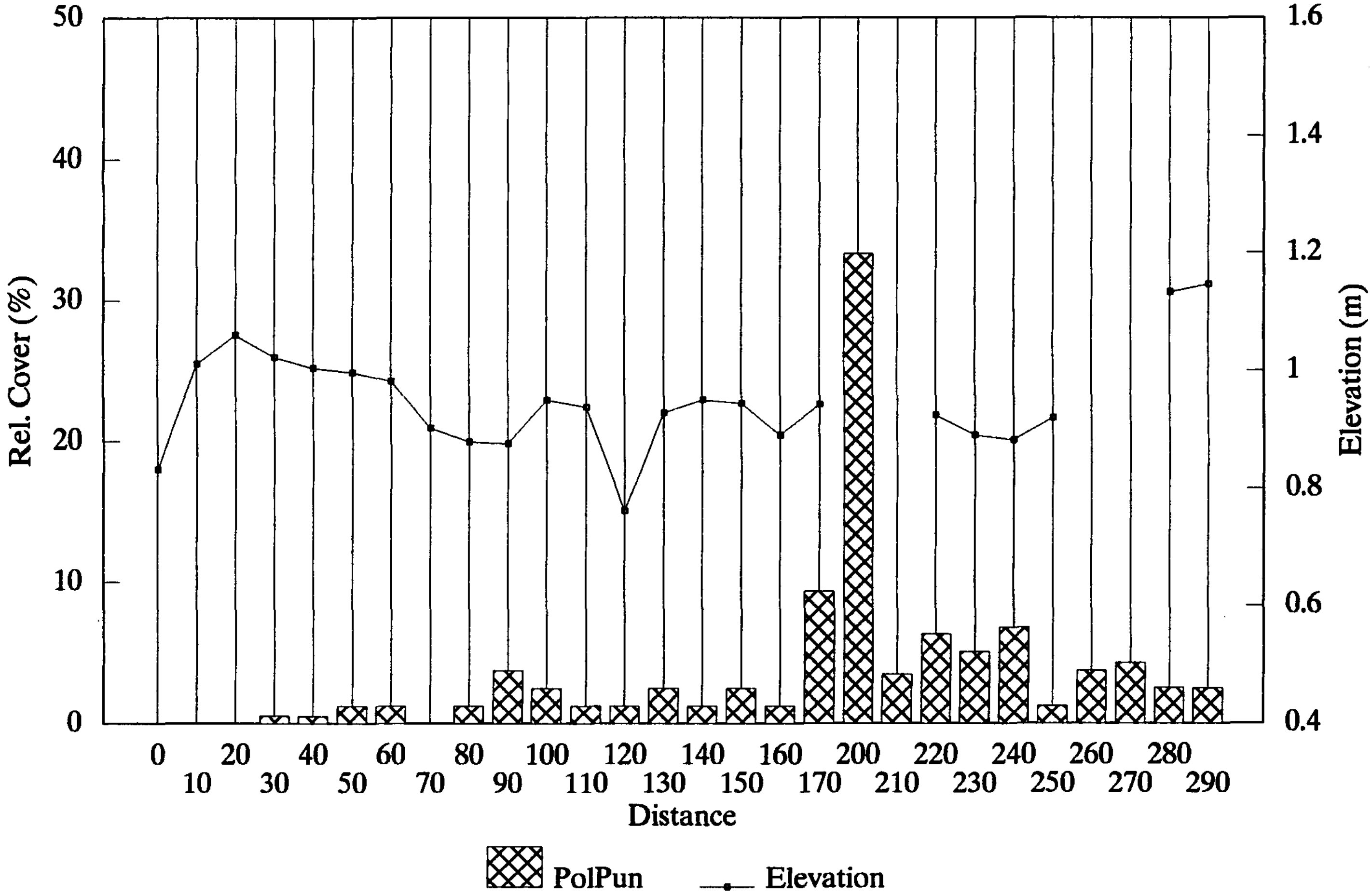


Note: Distance is measured in meters from the creek.

Figure 39. Distribution of PolPun along transect 2.

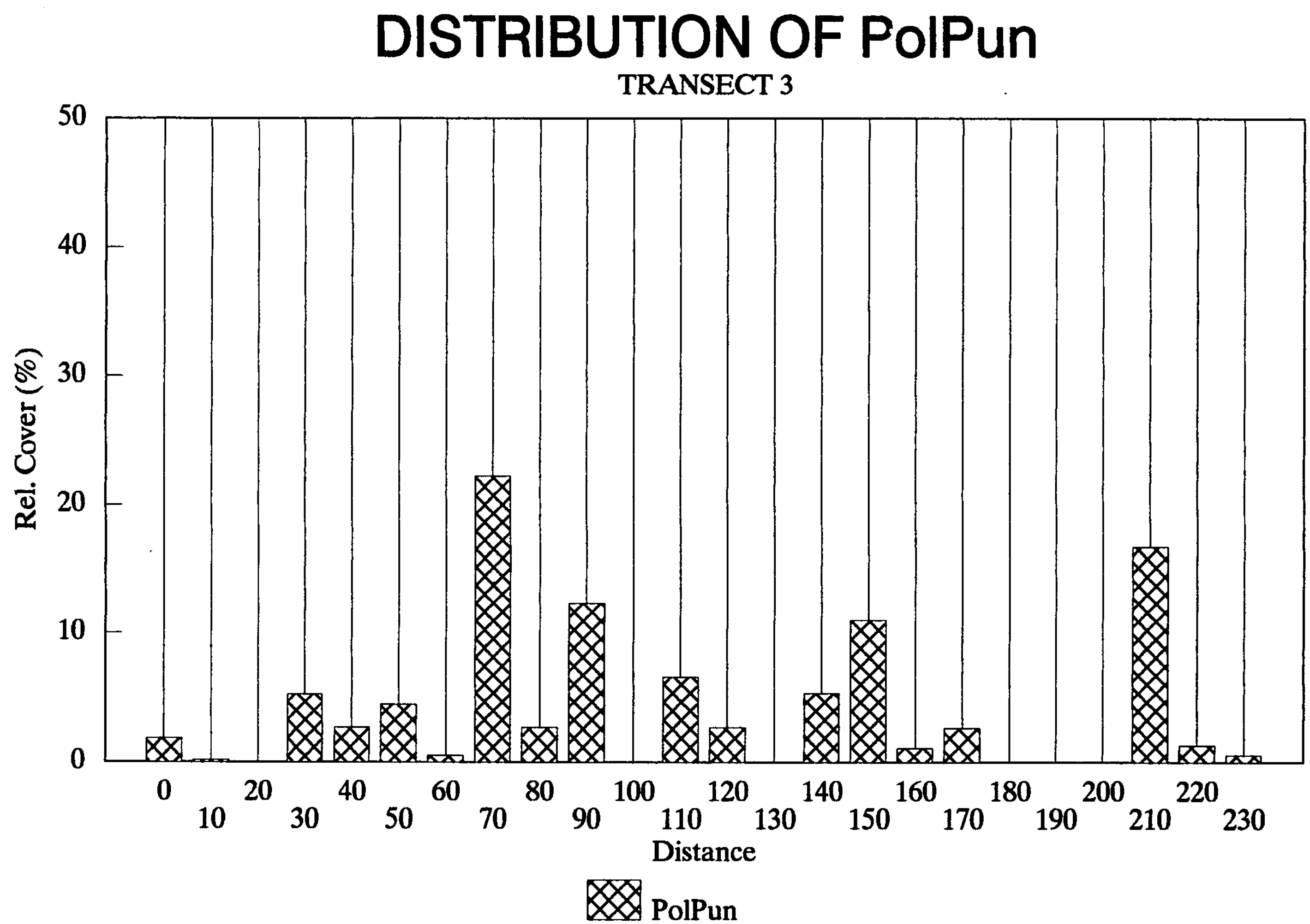
DISTRIBUTION OF PolPun

TRANSECT 2



Note: Distance is measured in meters from the creek.

Figure 40. Distribution of PolPun along transect 3.

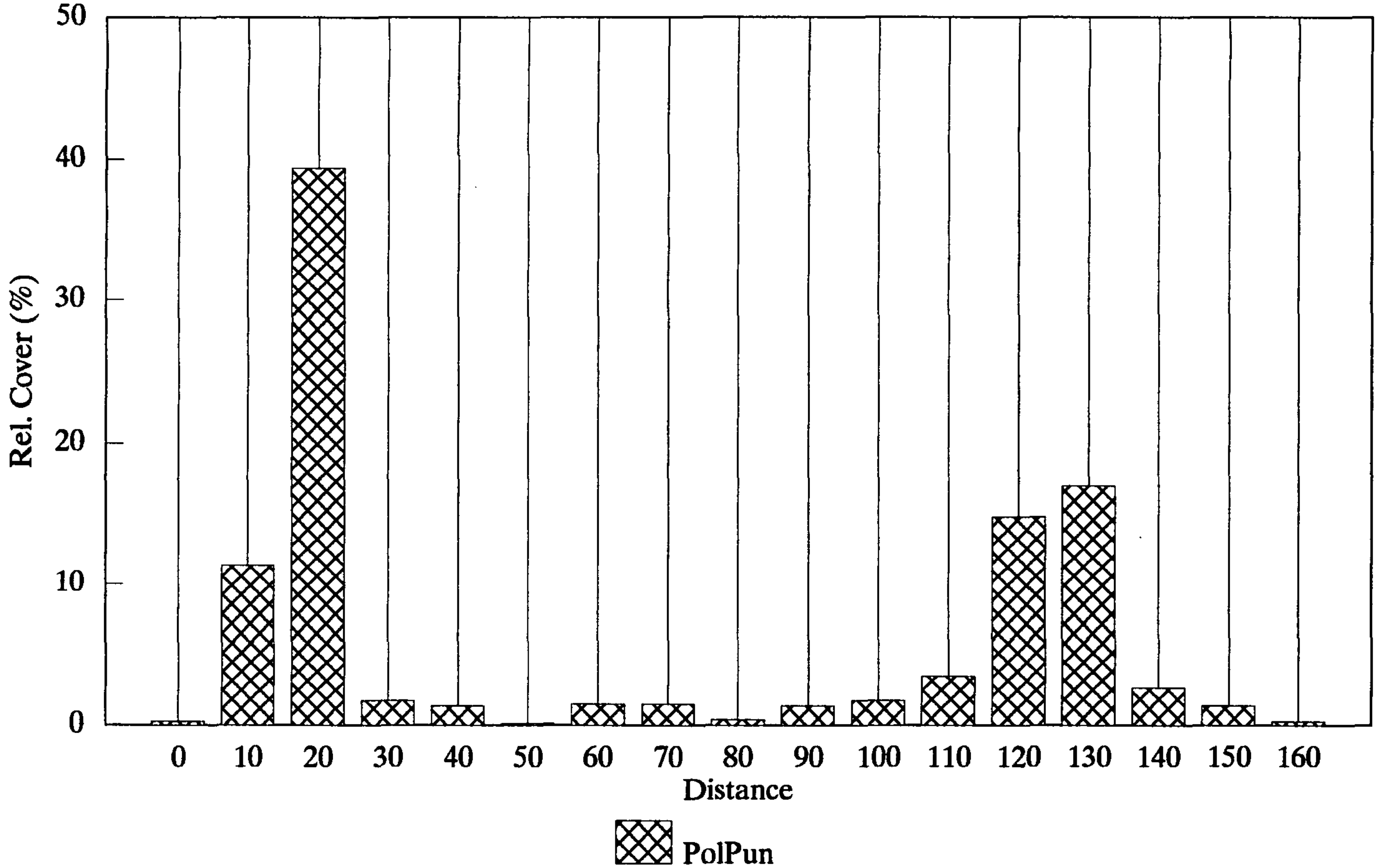


Note:1.Distance is measured in meters from the creek.
2. No elevation data available for this transect.

Figure 41. Distribution of PolPun along transect 4.

DISTRIBUTION OF PolPun

TRANSECT 4

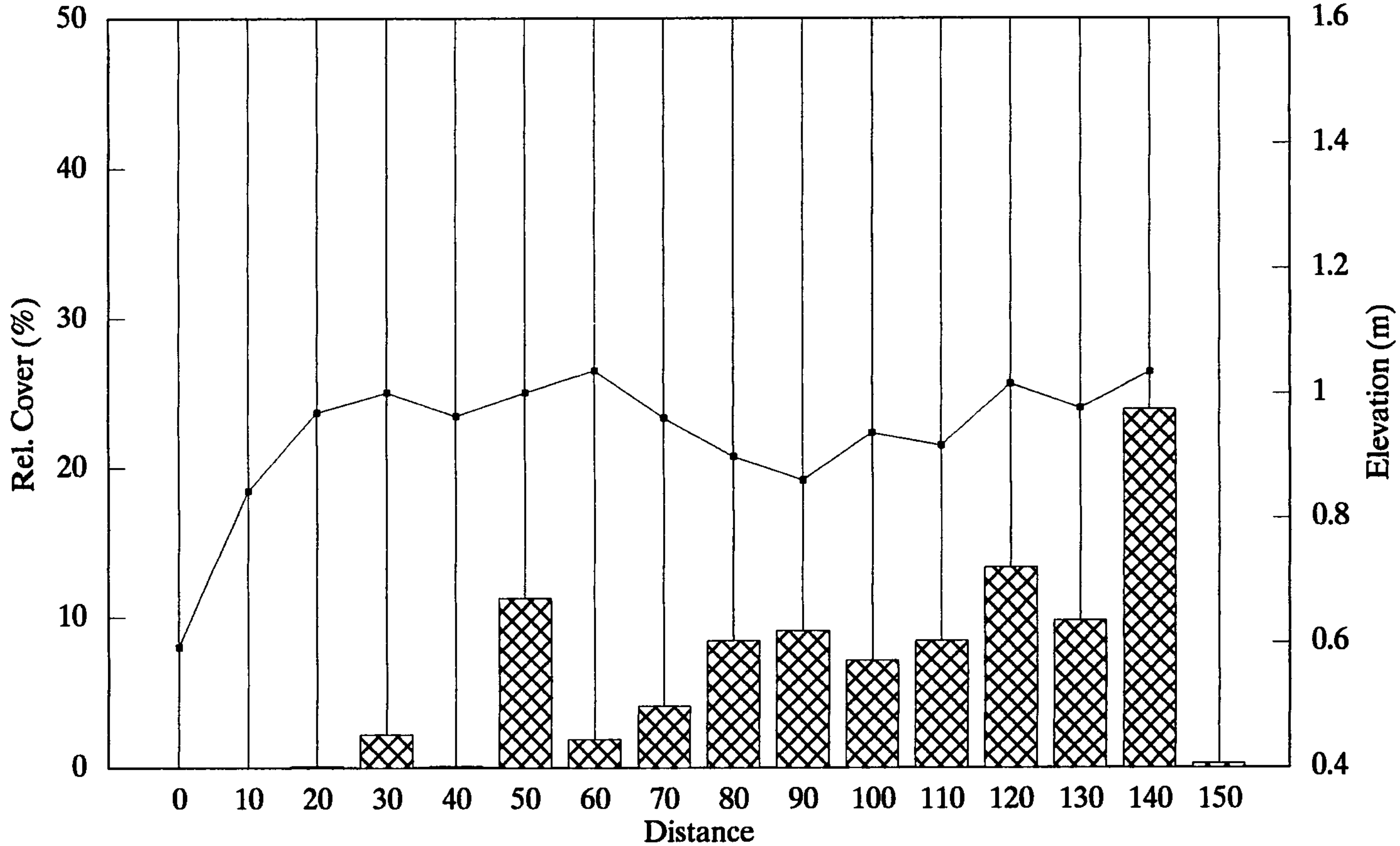


Note:1.Distance is measured in meters from the creek.
2.No elevation data available for this transect.

Figure 42. Distribution of PolPun along transect 5.

DISTRIBUTION OF PolPun

TRANSECT 5

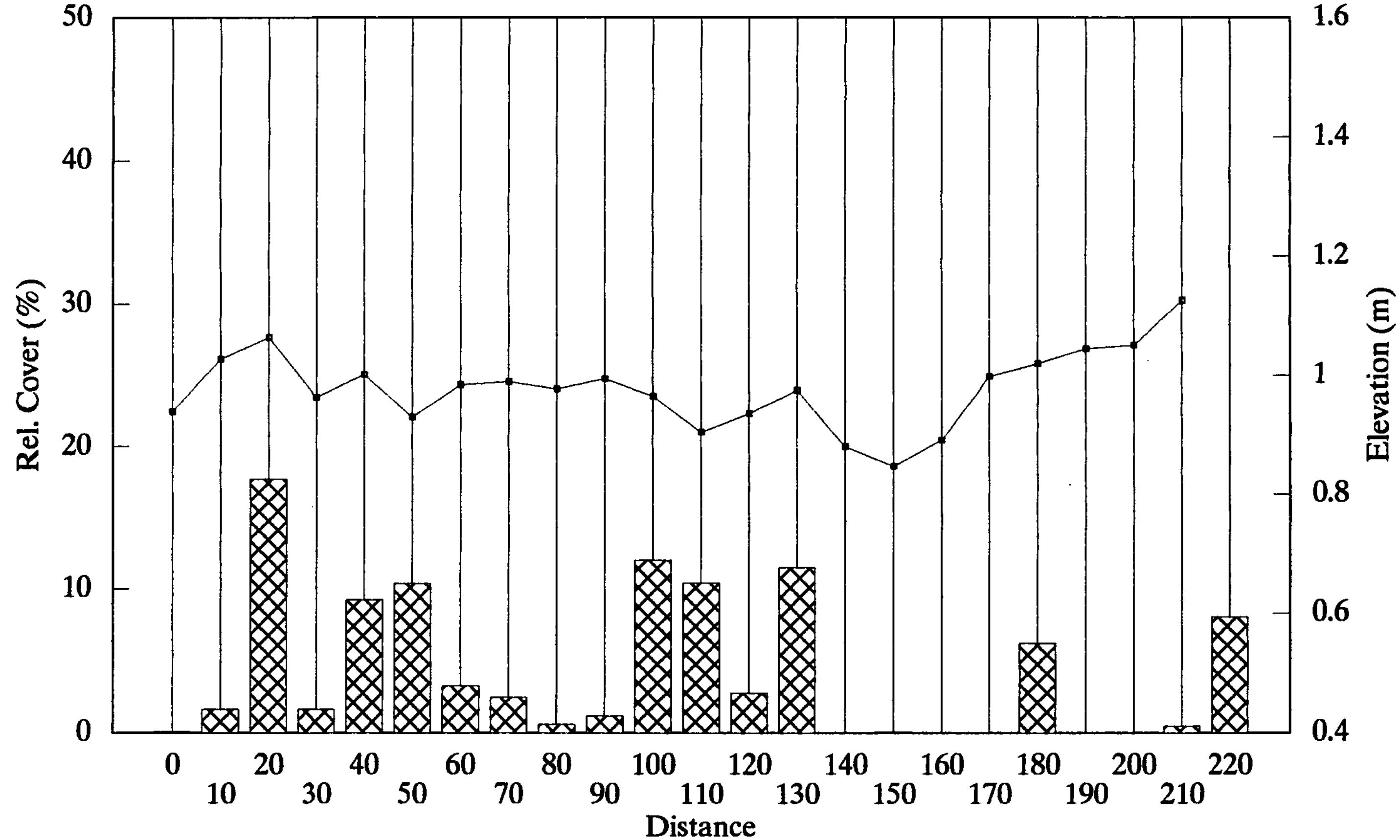


Note: Distance is measured in meters from the Pamunkey River.

Figure 43. Distribution of PolPun along transect 6.

DISTRIBUTION OF PolPun

TRANSECT 6

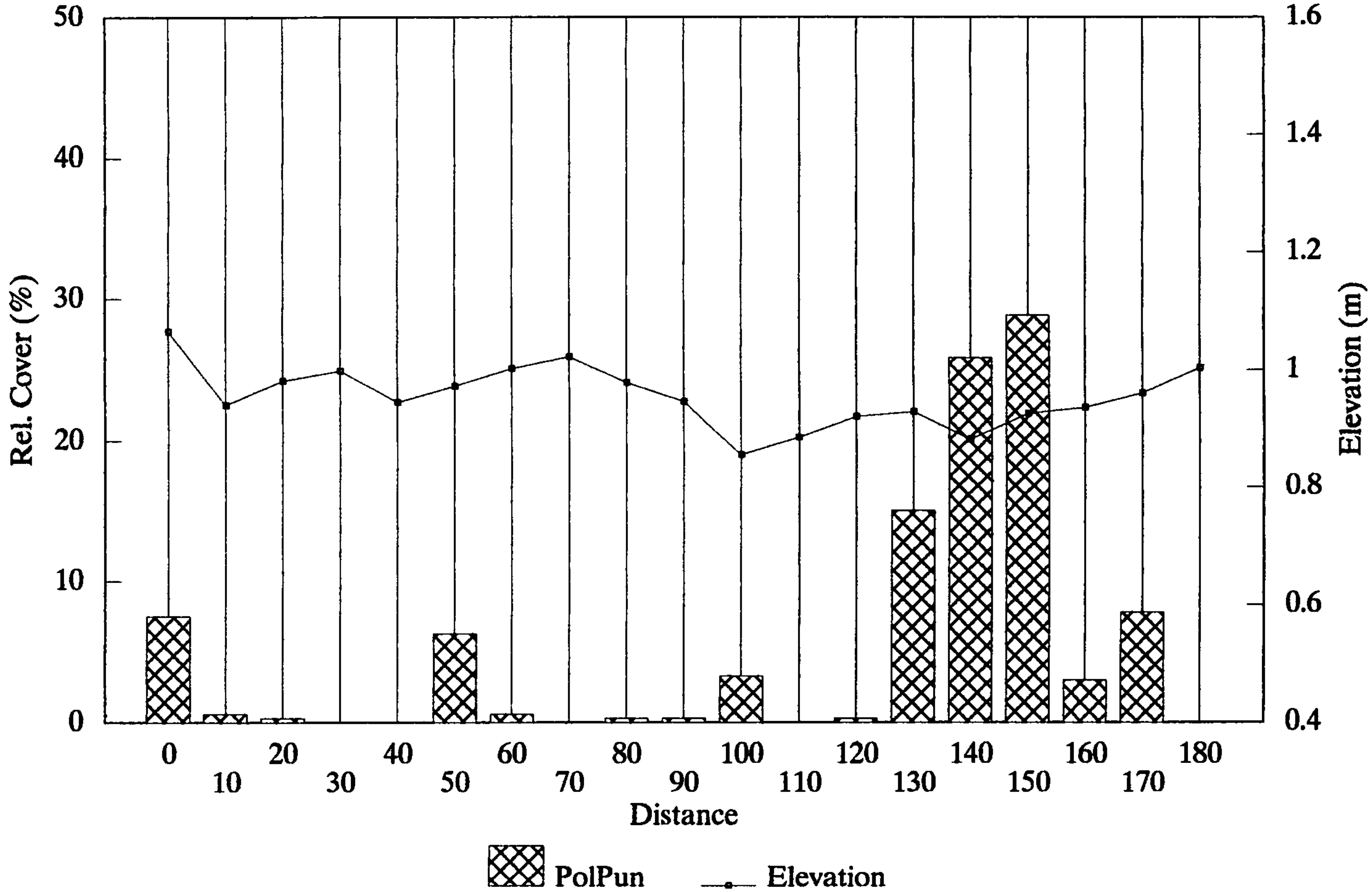


Note: Distance is measured in meters from the creek.

Figure 44. Distribution of PolPun along transect 7.

DISTRIBUTION OF PolPun

TRANSECT 7

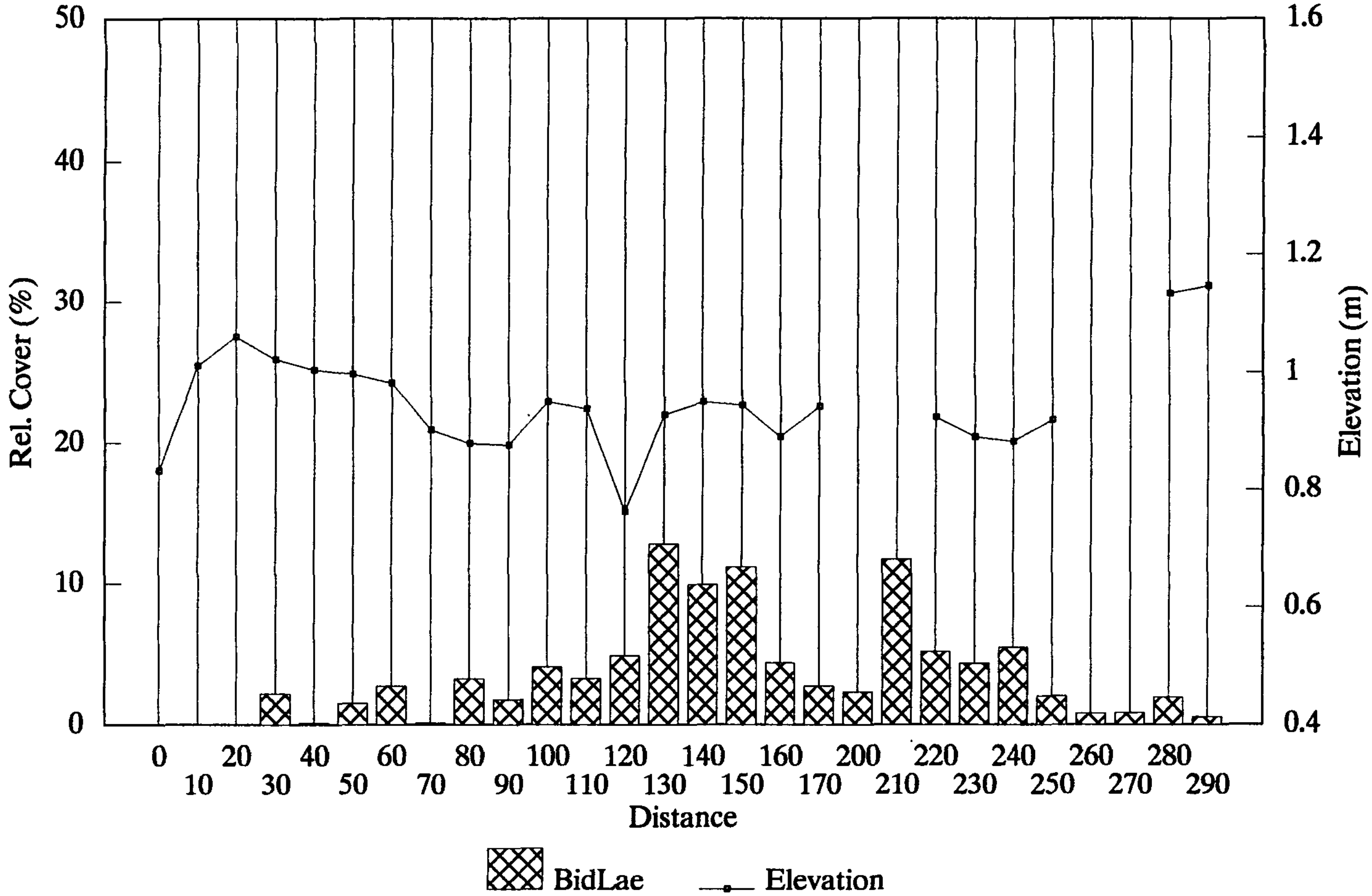


Note: Distance is measured in meters from the creek.

Figure 45. Distribution of BidLae along transect 2.

DISTRIBUTION OF BidLae

TRANSECT 2

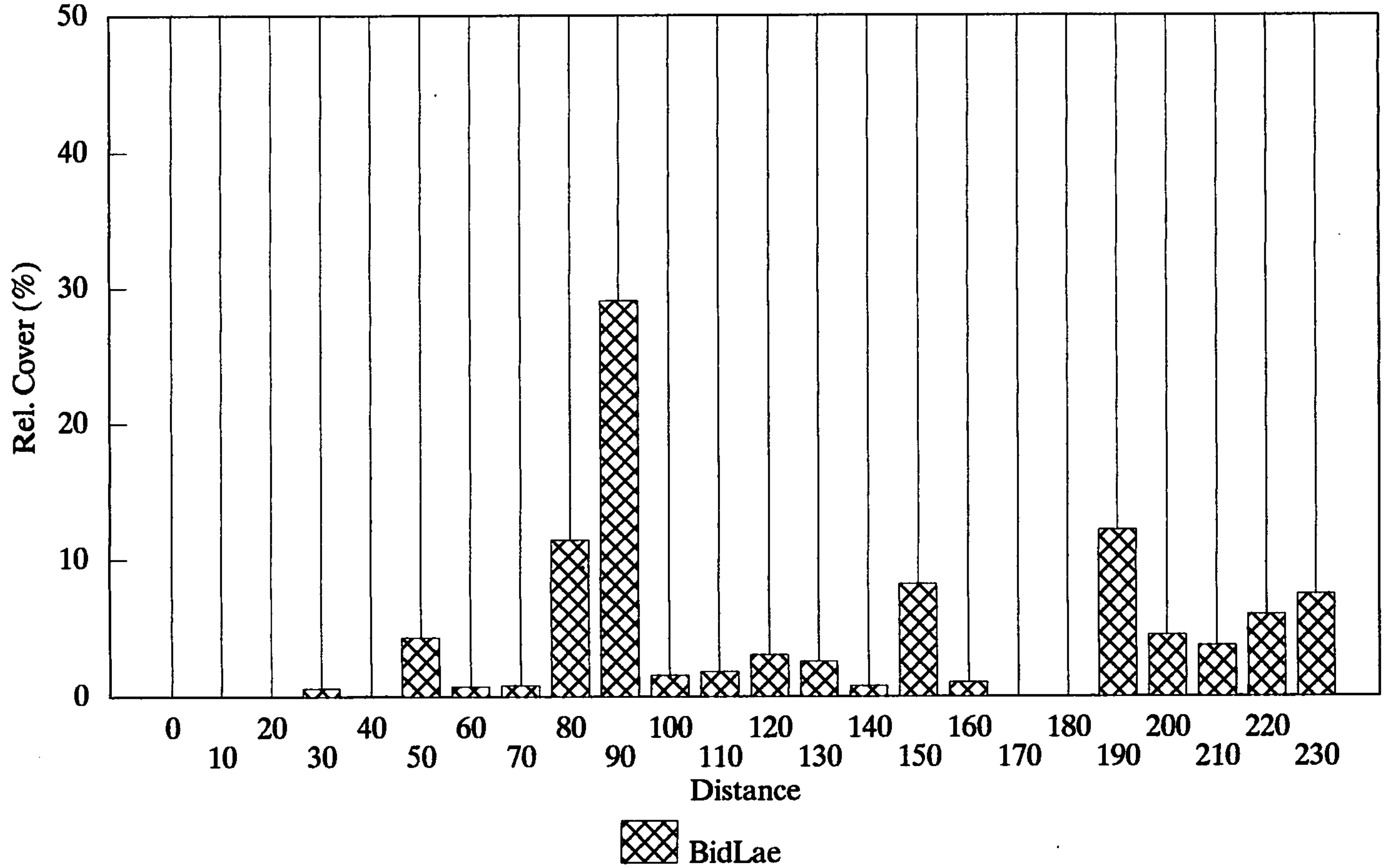


Note: Distance is measured in meters from the creek.

Figure 46. Distribution of BidLae along transect 3.

DISTRIBUTION OF BidLae

TRANSECT 3

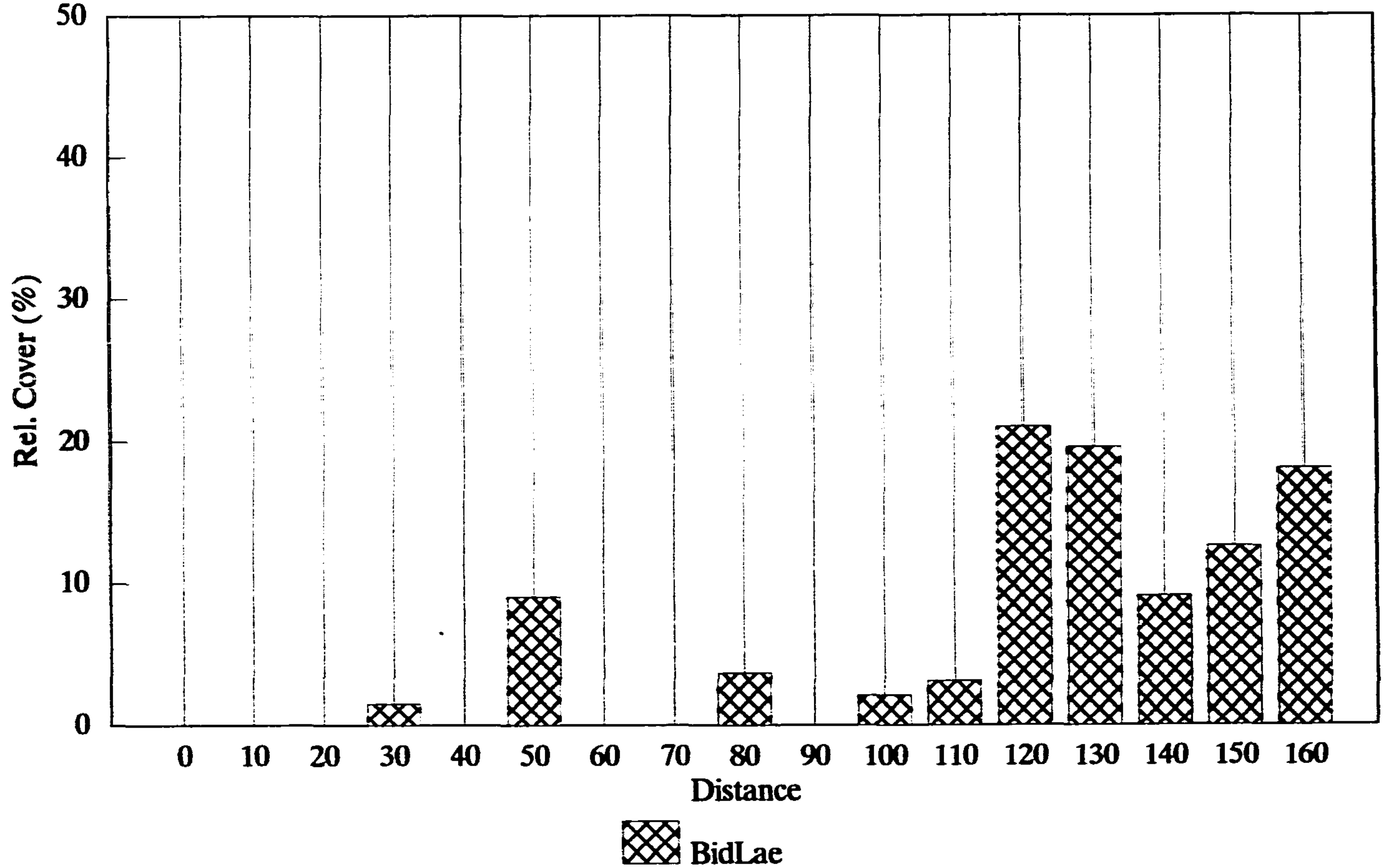


Note:1.Distance is measured in meters from the creek.
2. No elevation data available for this transect.

Figure 47. Distribution of BidLae along transect 4.

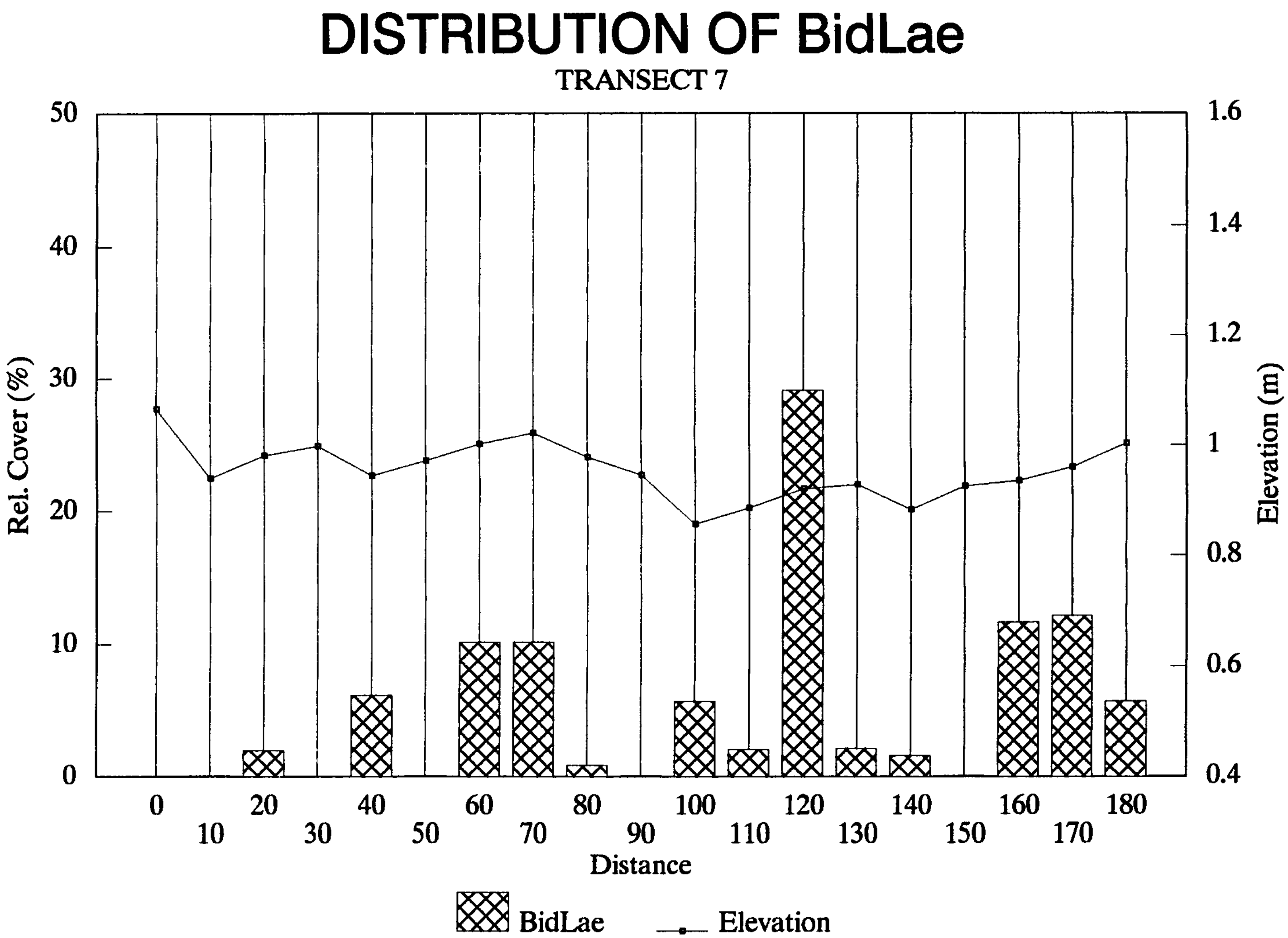
DISTRIBUTION OF BidLae

TRANSECT 4



Note:1.Distance is measured in meters from the creek.
2.No elevation data available for this transect.

Figure 48. Distribution of BidLaė along transect 7.

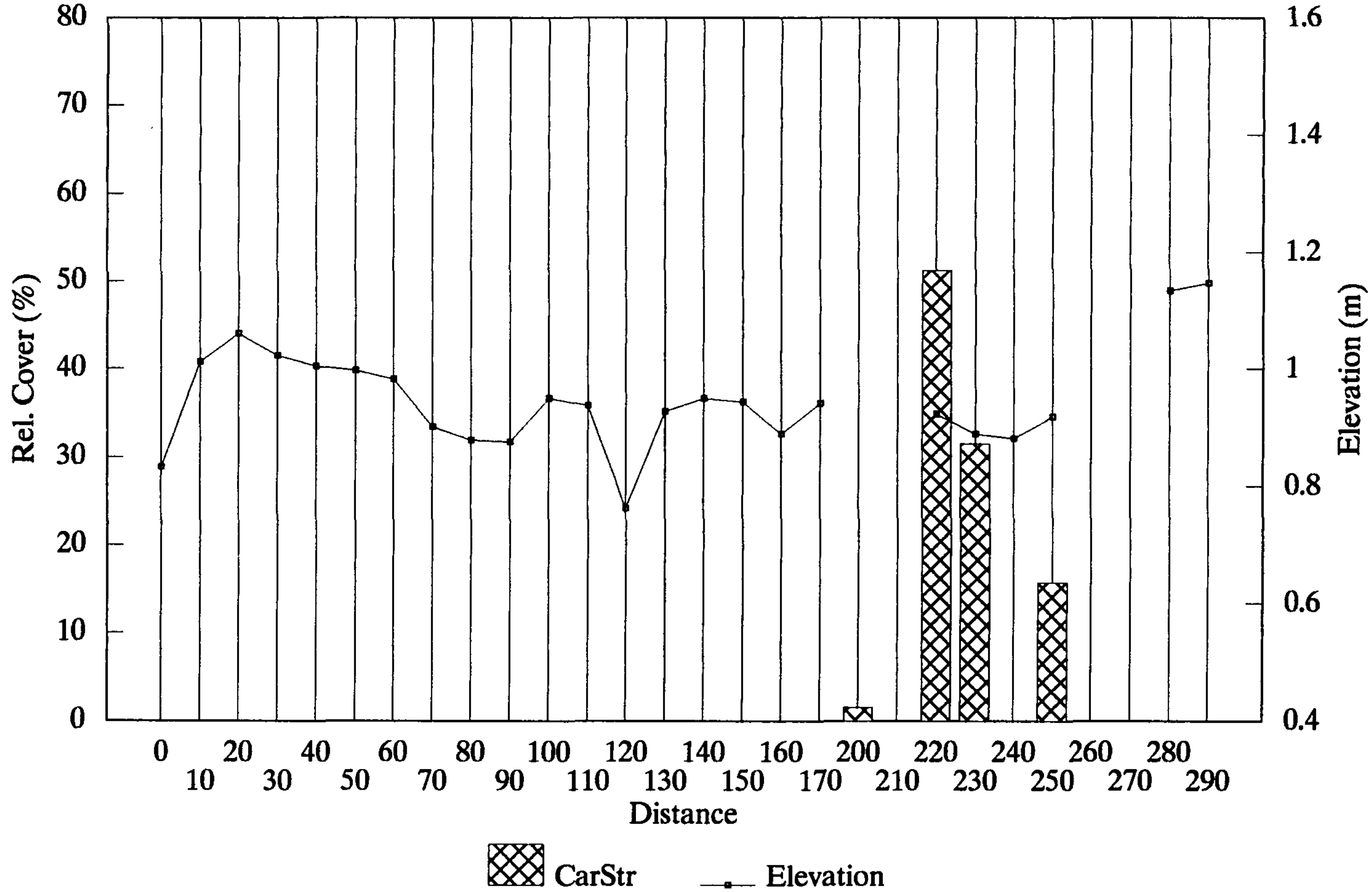


Note: Distance is measured in meters from the creek.

Figure 49. Distribution of CarStr along transect 2.

DISTRIBUTION OF CarStr

TRANSECT 2

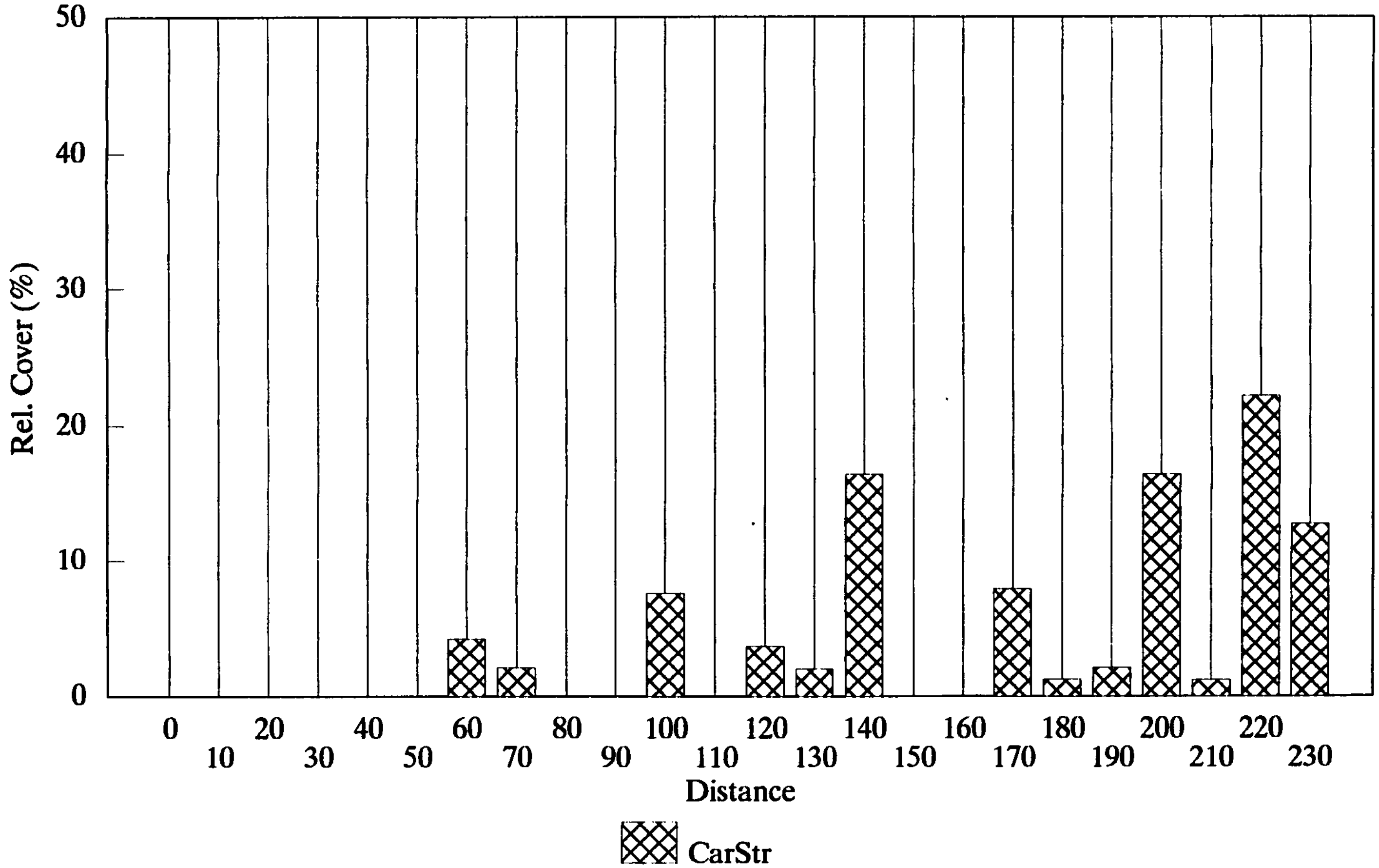


Note: Distance is measured in meters from the creek.

Figure 50. Distribution of CarStr along transect 3.

DISTRIBUTION OF CarStr

TRANSECT 3

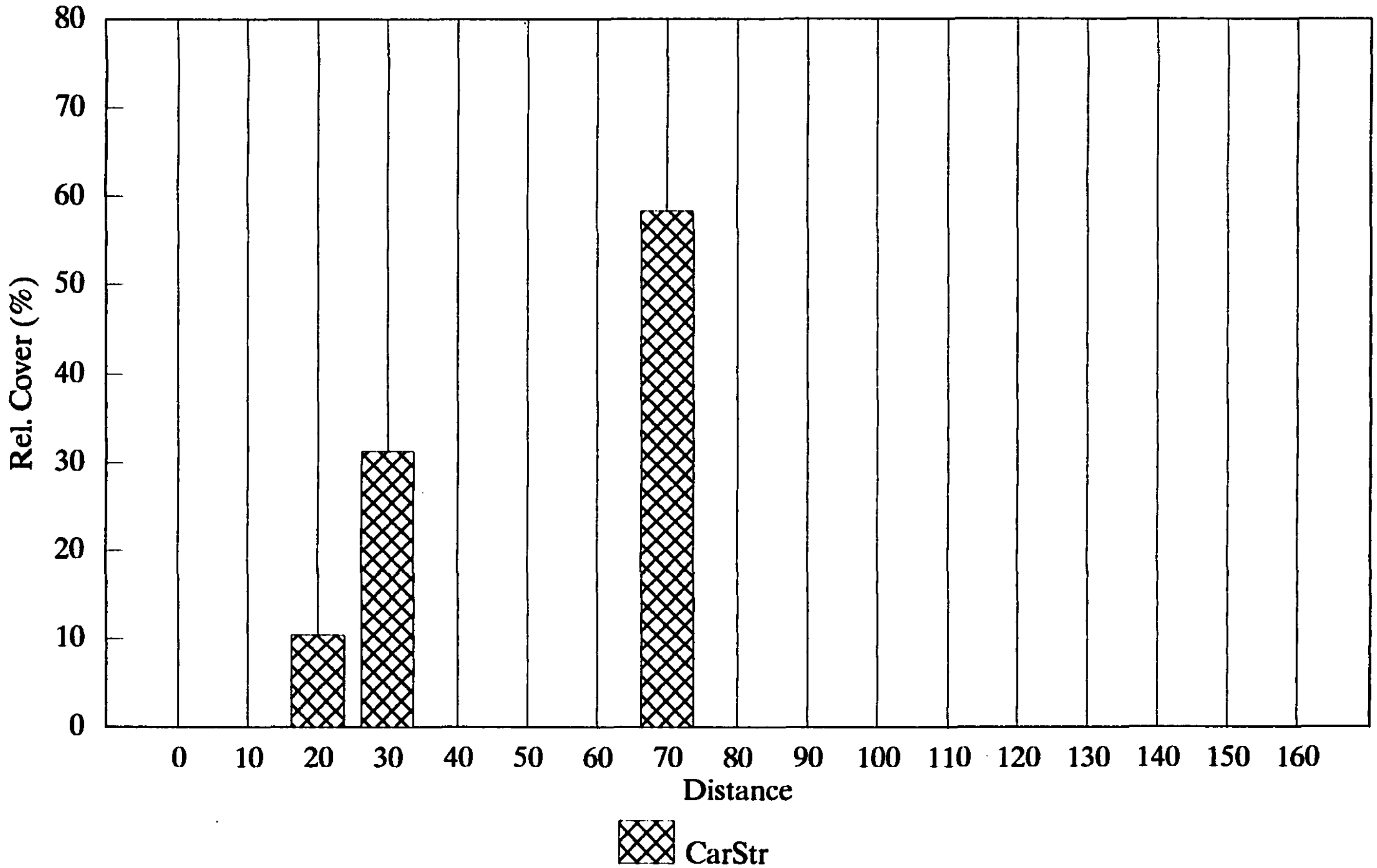


Note: 1. Distance is measured in meters from the creek.
2. No elevation data available for this transect.

Figure 51. Distribution of CarStr along transect 4.

DISTRIBUTION OF CarStr

TRANSECT 4

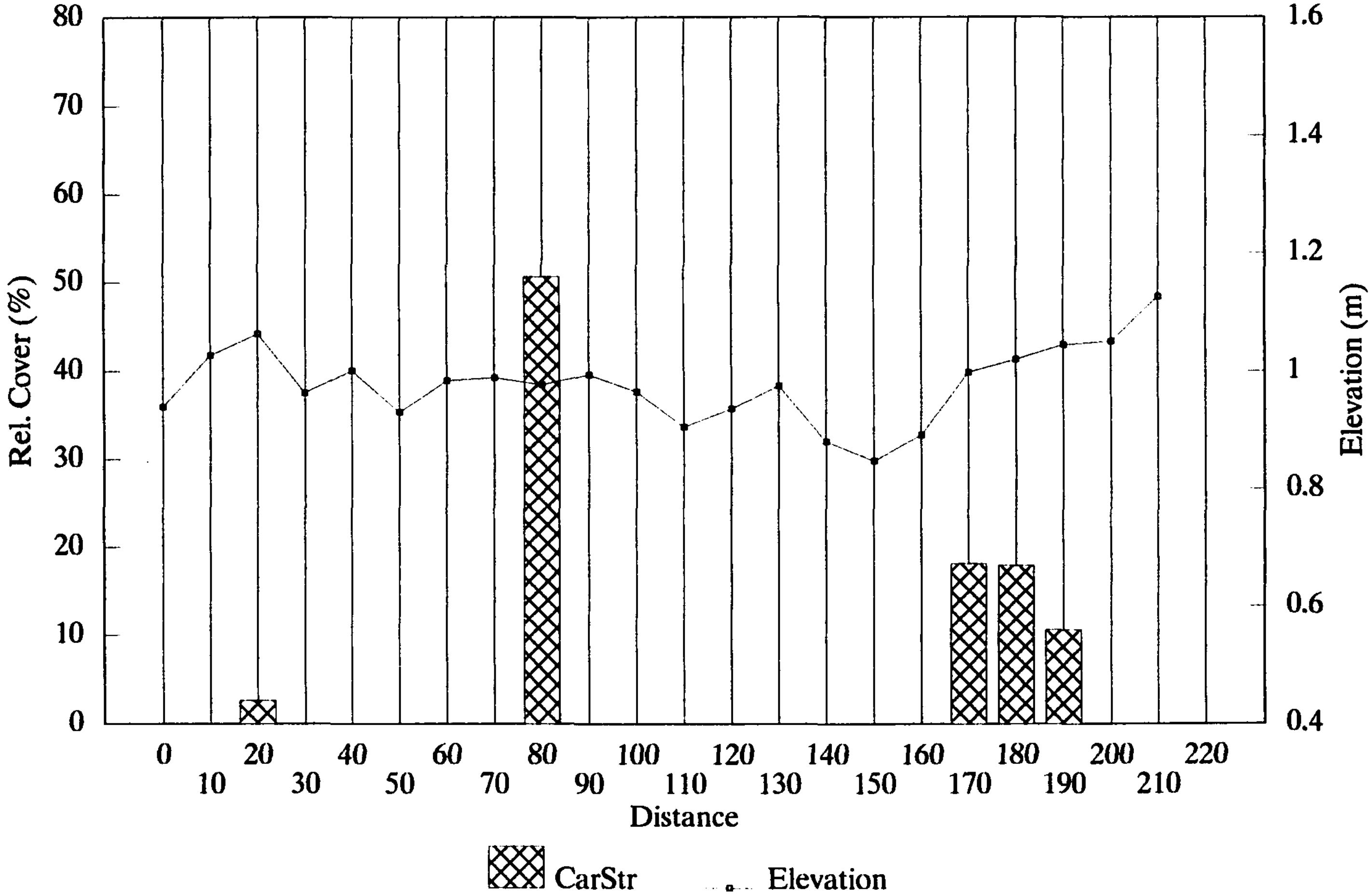


Note:1.Distance is measured in meters from the creek.
2.No elevation data available for this transect.

Figure 52. Distribution of CarStr along transect 6.

DISTRIBUTION OF CarStr

TRANSECT 6

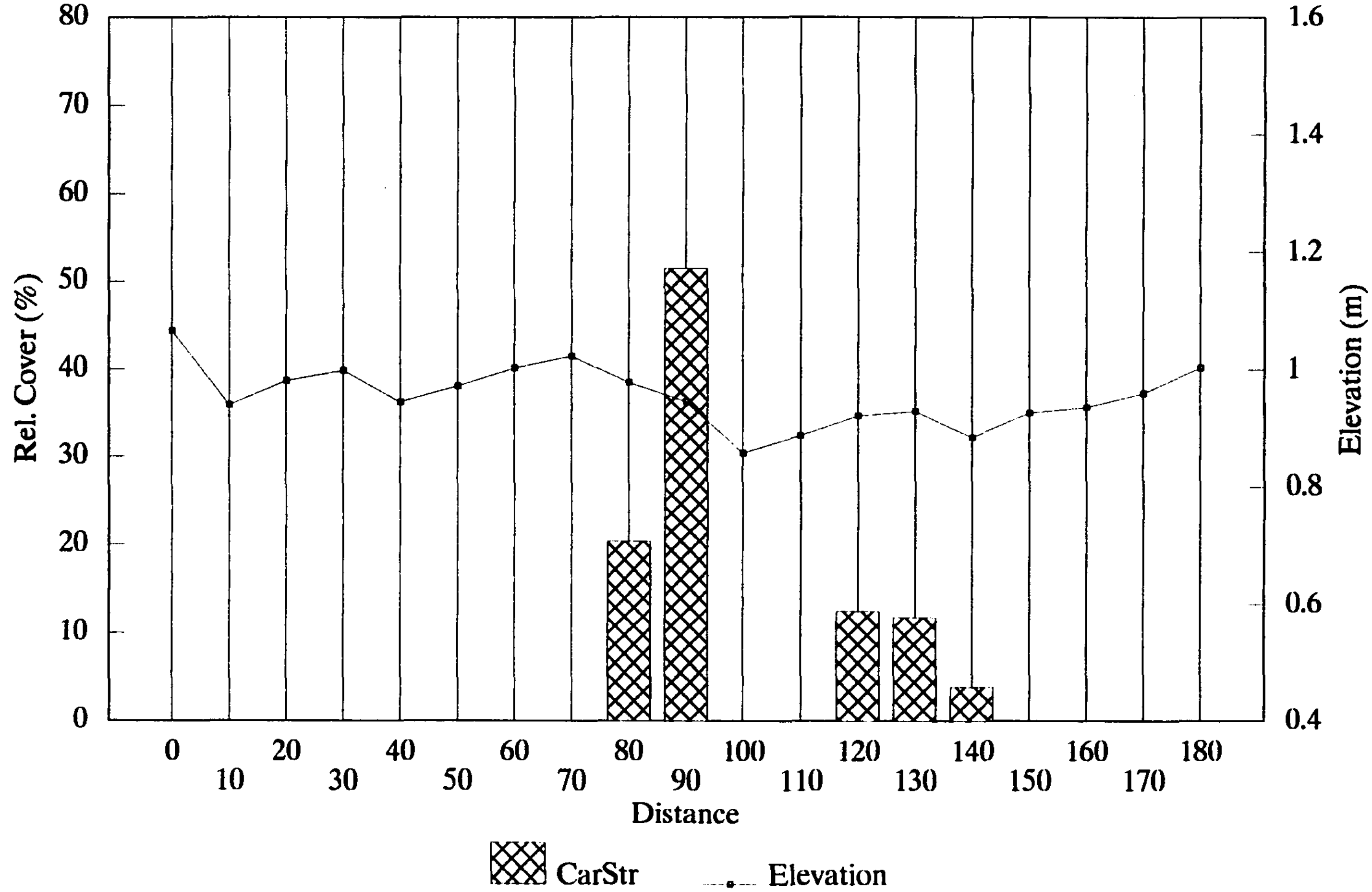


Note: Distance is measured in meters from the creek.

Figure 53. Distribution of CarStr along transect 7.

DISTRIBUTION OF CarStr

TRANSECT 7



Note: Distance is measured in meters from the creek.

mean annual frequency of 16.0 (Table 6) and an uneven distribution. *E. walteri* occurred in five of the seven transects (Figures 54 to 58). *Amaranthus cannabinus* occurred in all seven transects, had an uneven, widely distributed pattern (Figures 59 to 65), and a mean annual frequency of 16.7% (Table 6).

Interspecific relationships are given in Table 7. Of the 70 possible combinations, 43 (61.7%) were significant (P=0.05), of which 24 showed a negative and 19 a positive relationship between species.

Marsh Topography and Species Distribution

Three distinct topographic zones were readily identifiable in the marsh (Figure 66). Distinction was made by species content and physical position in the marsh. These zones were:

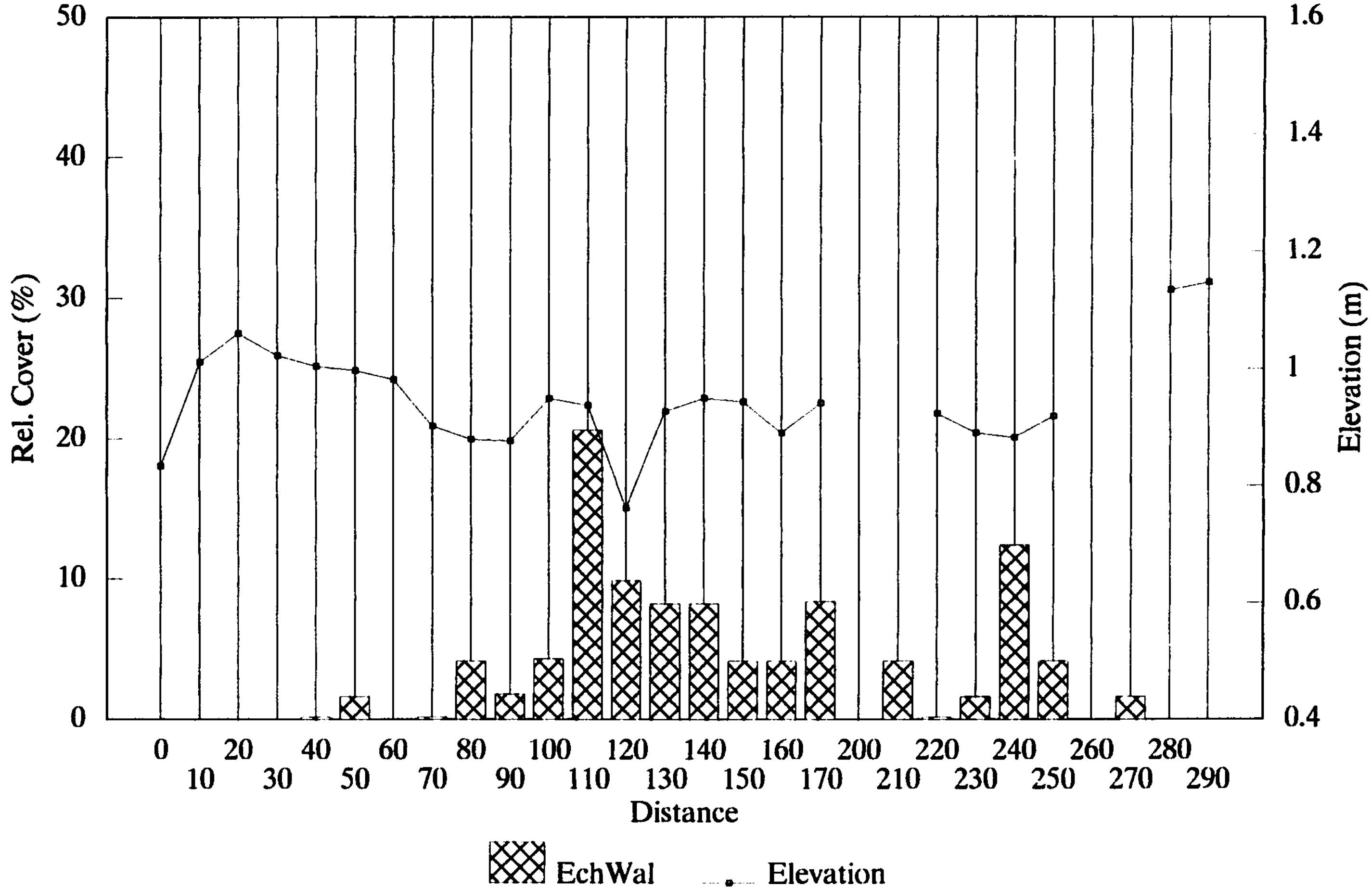
1) the creek zone, dominated by *Peltandra virginica*;
2) the levee-overwash zone, dominated by *Spartina cynosuroides*;
3) the mixed marsh zone, a heterogenous area dominated by more than one species.

The creek zone was directly exposed to tidal actions including flooding, scouring and sedimentation. Physically, the zone consisted of a fringe one to ten meters wide that sloped downward toward the river on an approximately eight to ten degree angle. The waterward limit of the

Figure 54. Distribution of EchWal along transect 2.

DISTRIBUTION OF EchWal

TRANSECT 2

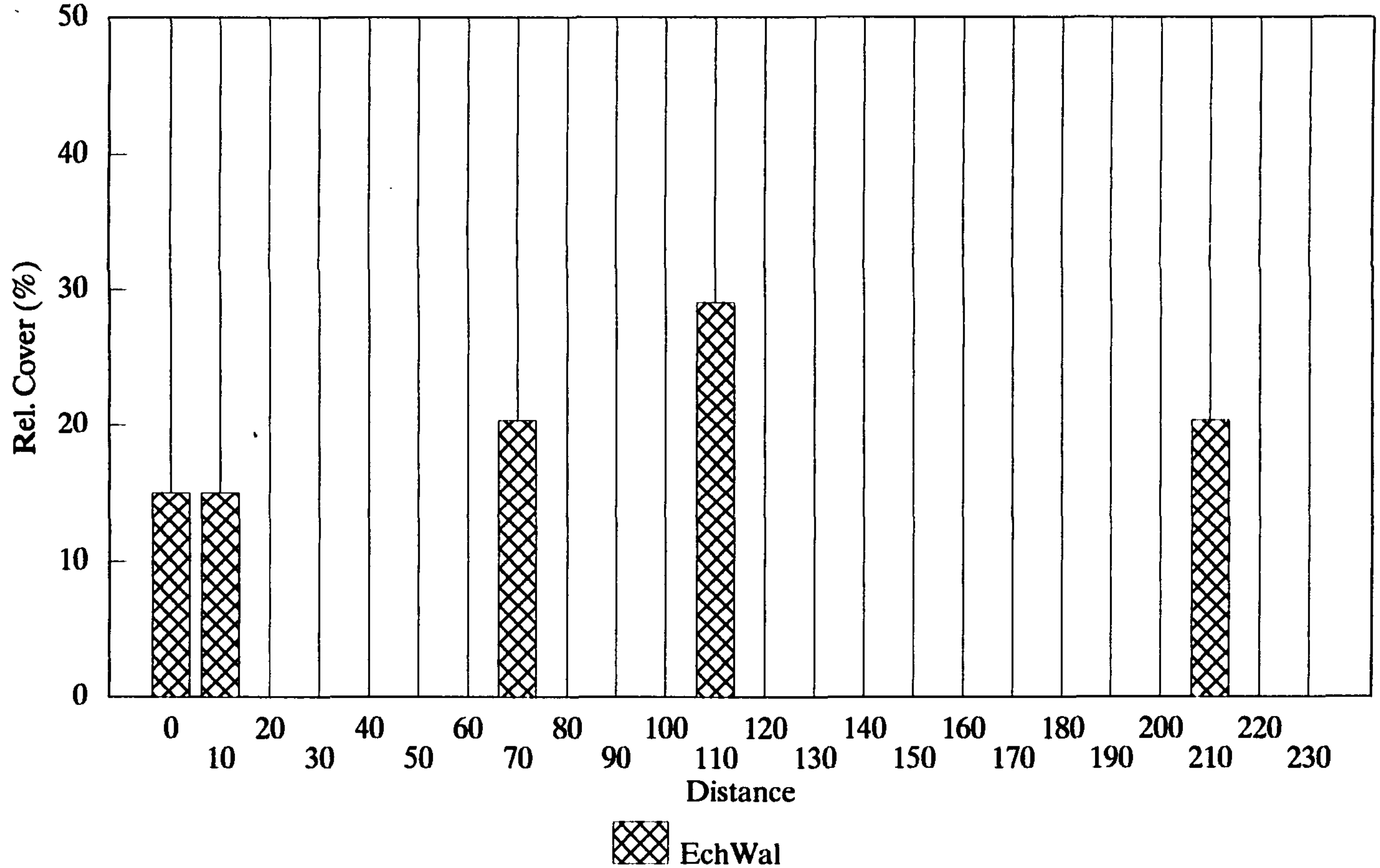


Note: Distance is measured in meters from the creek.

Figure 55. Distribution of EchWal along transect 3.

DISTRIBUTION OF EchWal

TRANSECT 3

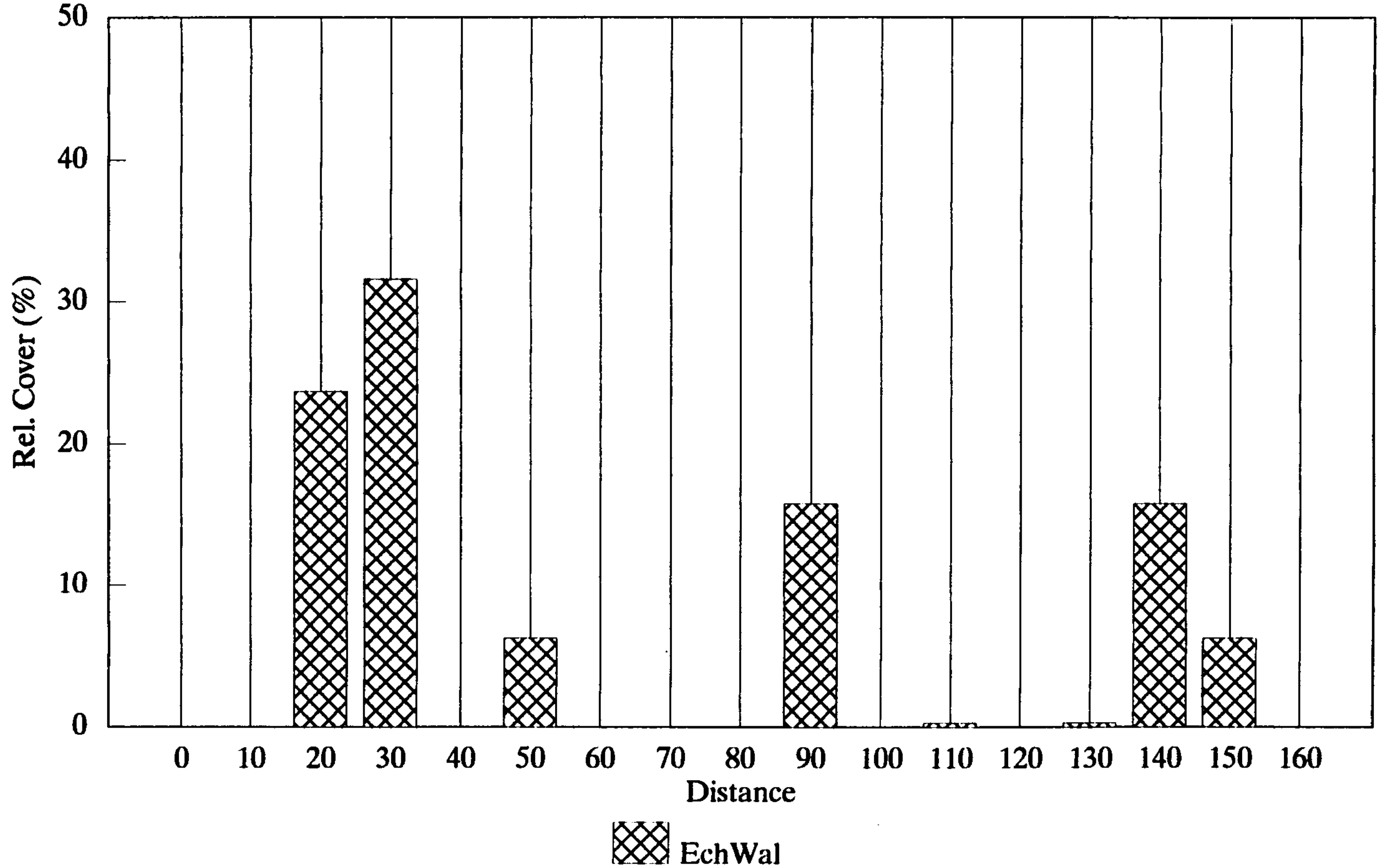


Note: 1. Distance is measured in meters from the creek.
2. No elevation data available for this transect.

Figure 56. Distribution of EchWal along transect 4.

DISTRIBUTION OF EchWal

TRANSECT 4

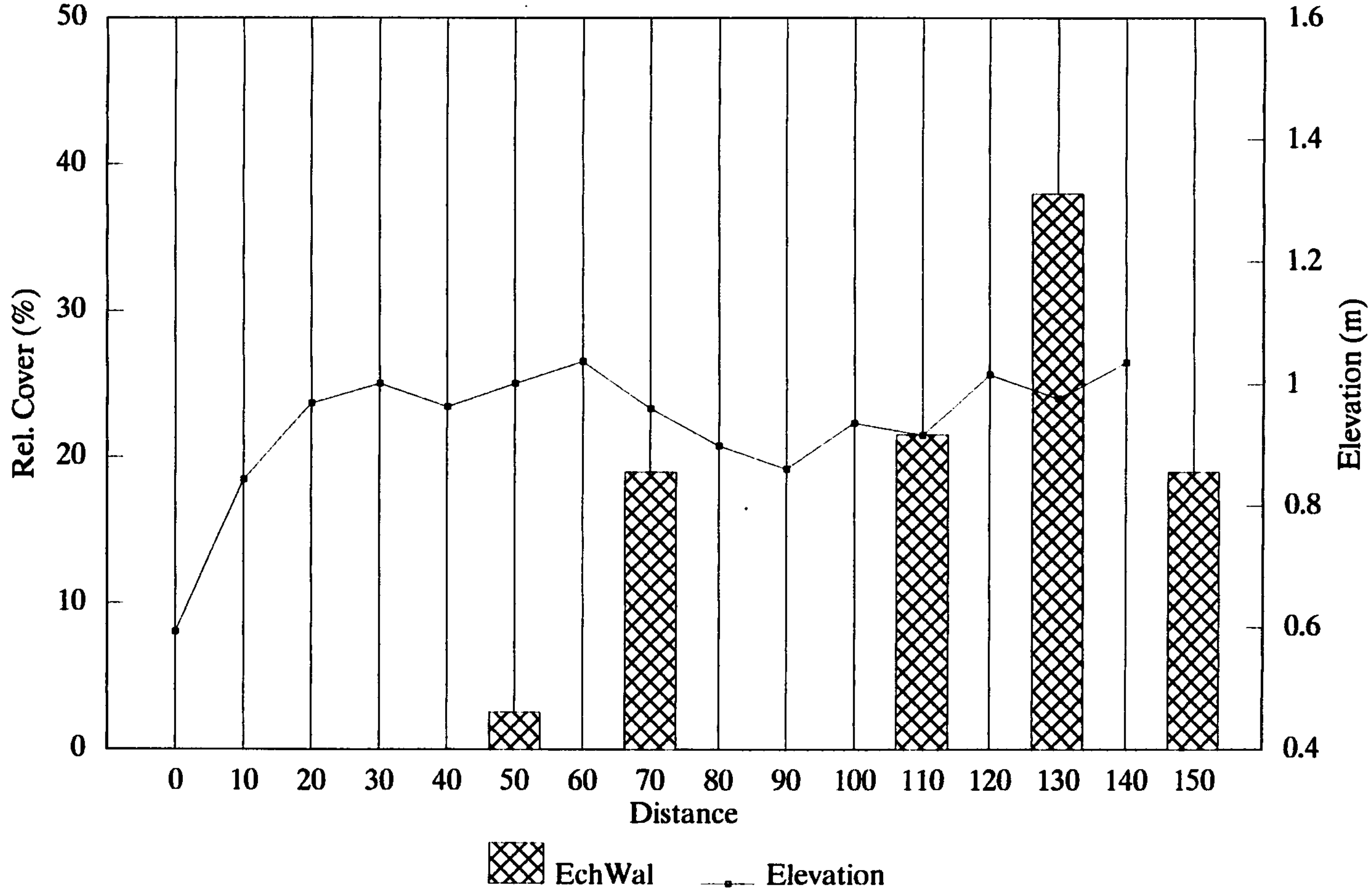


Note: 1.Distance is measured in meters from the creek.
2.No elevation data available for this transect.

Figure 57. Distribution of EchWal along transect 5.

DISTRIBUTION OF EchWal

TRANSECT 5

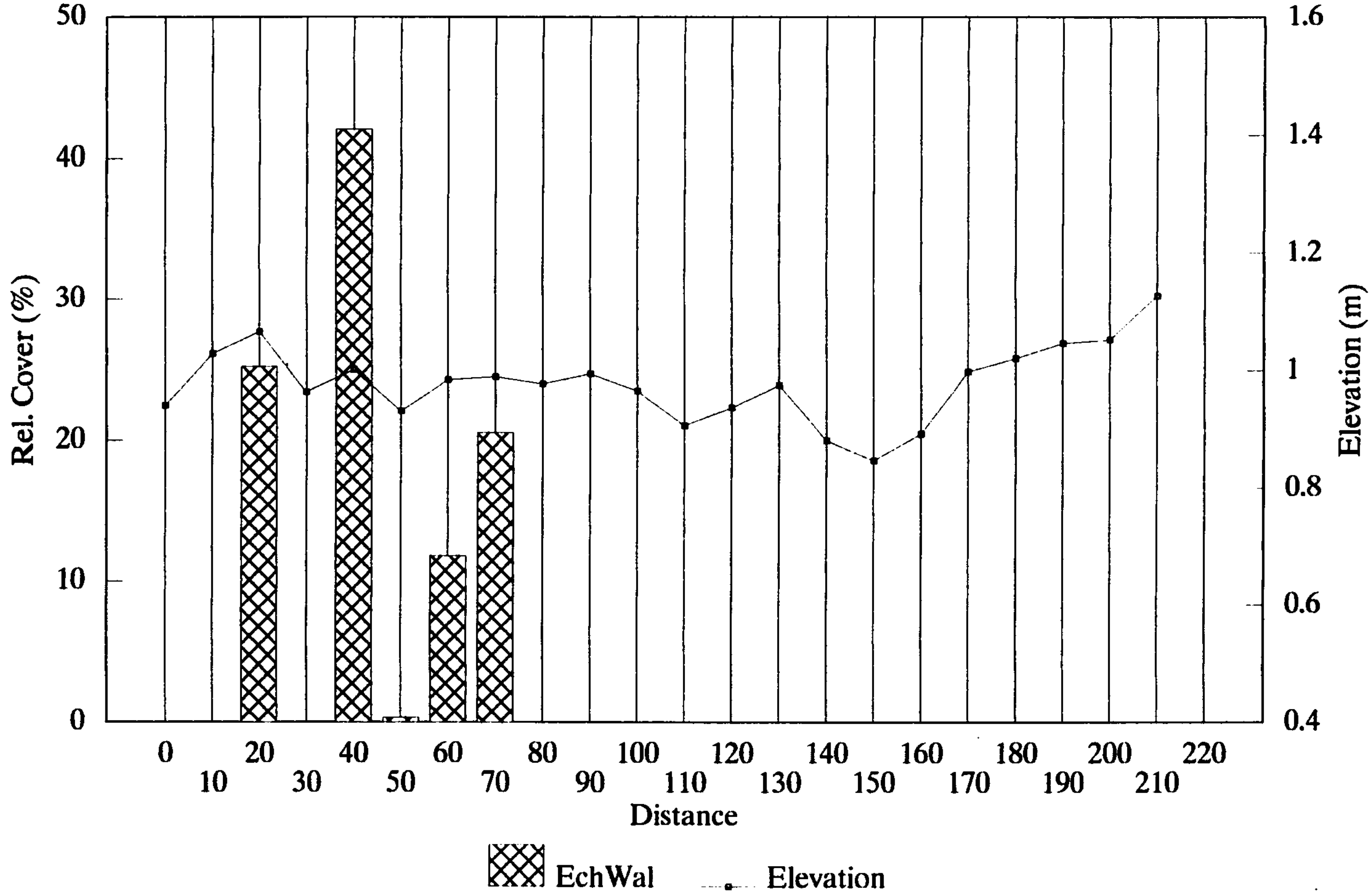


Note: Distance is measured in meters from the Pamunkey River.

Figure 58. Distribution of EchWal along transect 6.

DISTRIBUTION OF EchWal

TRANSECT 6

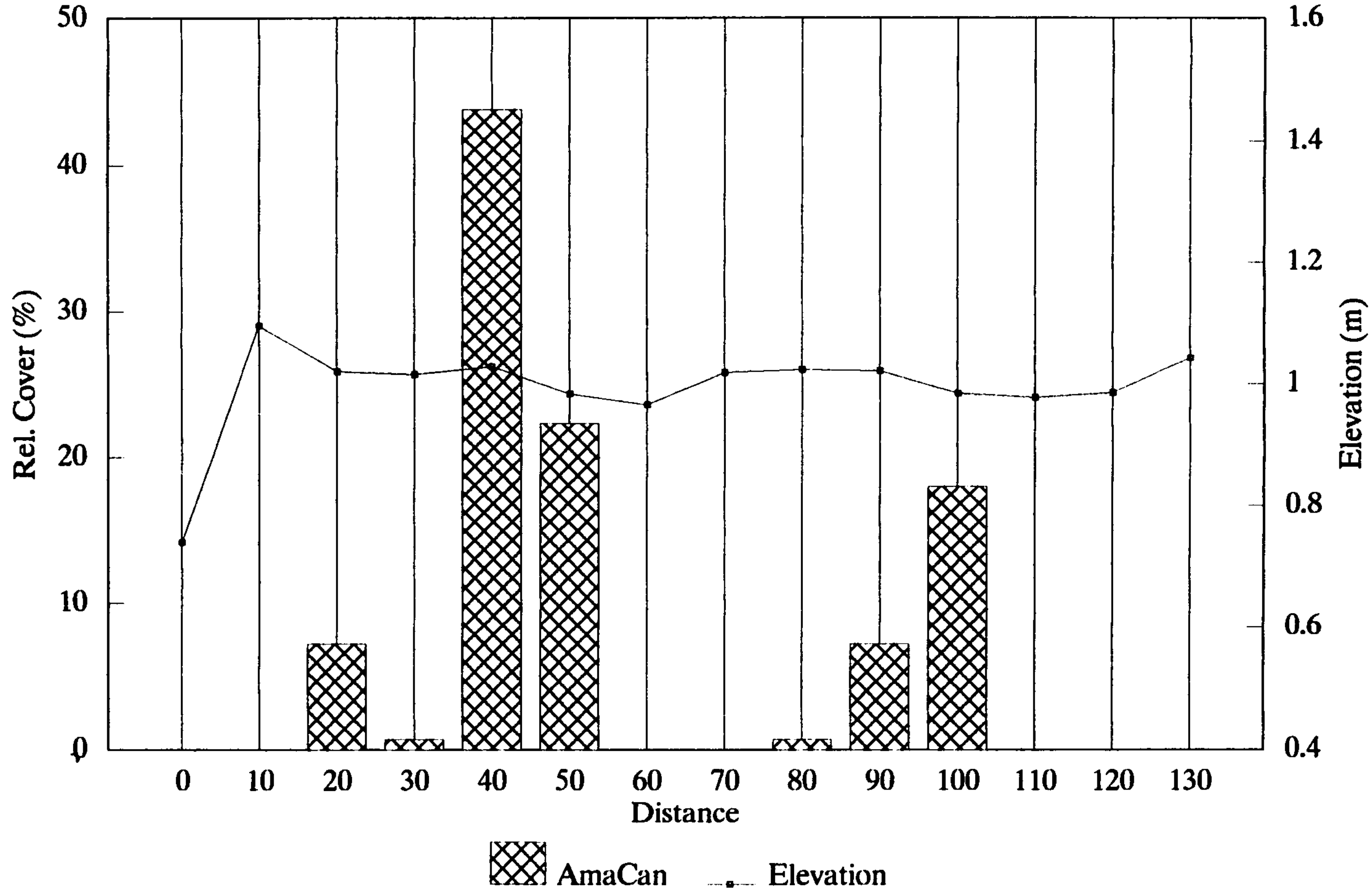


Note: Distance is measured in meters from the creek.

Figure 59. Distribution of AmaCan along transect 1.

DISTRIBUTION OF AmaCan

TRANSECT 1

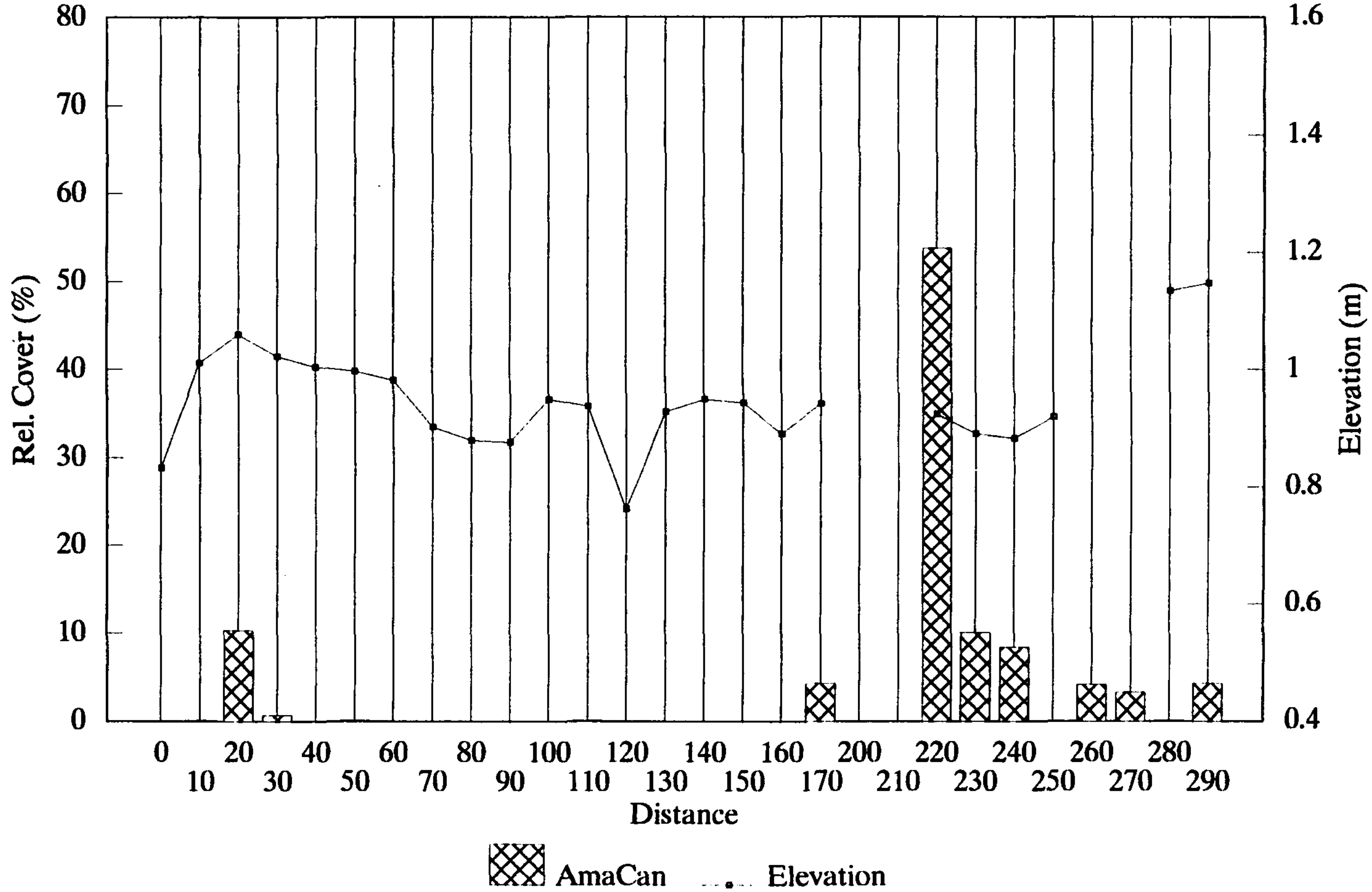


Note: Distance is measured in meters from the creek.

Figure 60. Distribution of AmaCan along transect 2.

DISTRIBUTION OF AmaCan

TRANSECT 2

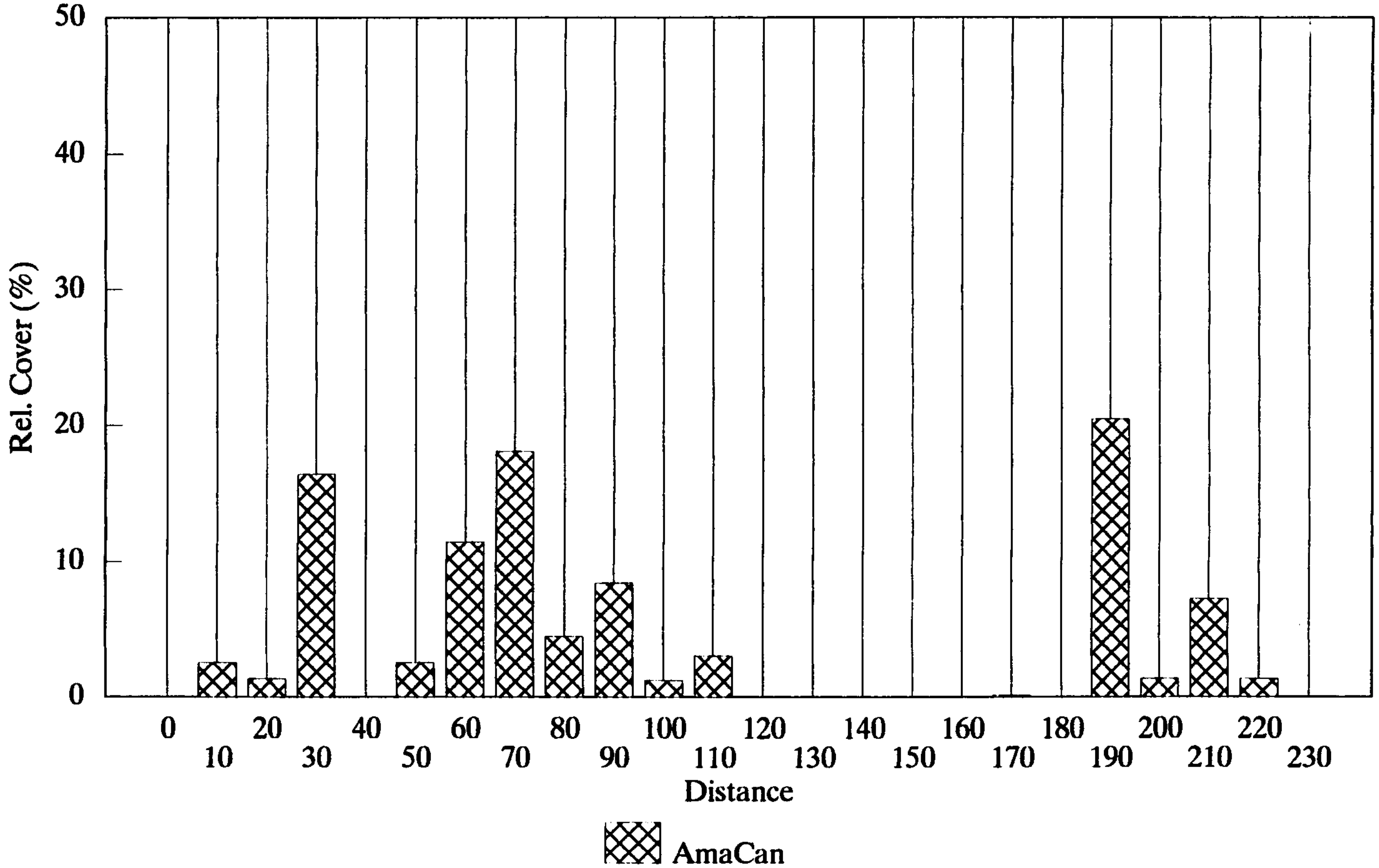


Note: Distance is measured in meters from the creek.

Figure 61. Distribution of AmaCan along transect 3.

DISTRIBUTION OF AmaCan

TRANSECT 3

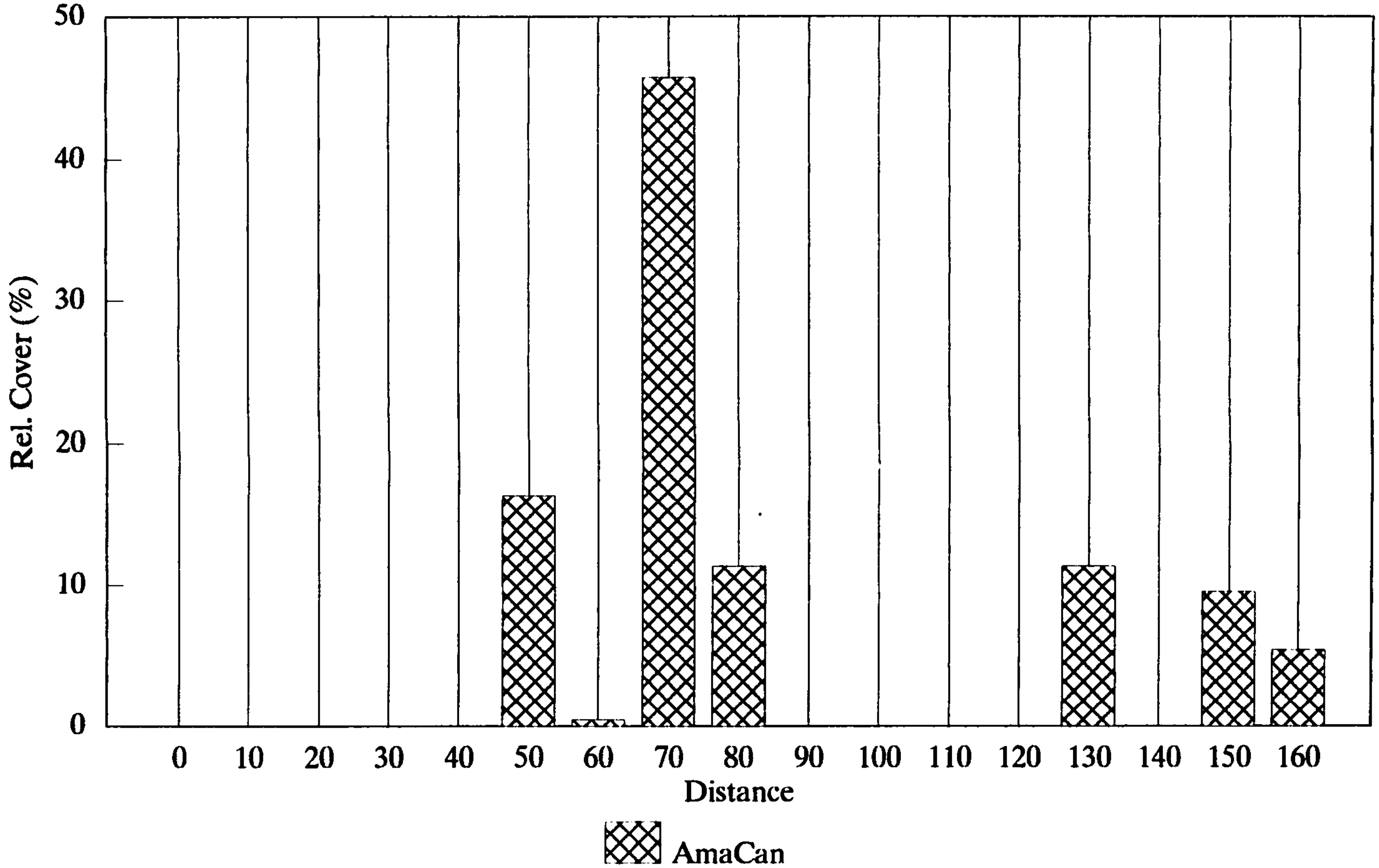


Note: 1. Distance is measured in meters from the creek.
2. No elevation data available for this transect.

Figure 62. Distribution of AmaCan along transect 4.

DISTRIBUTION OF AmaCan

TRANSECT 4

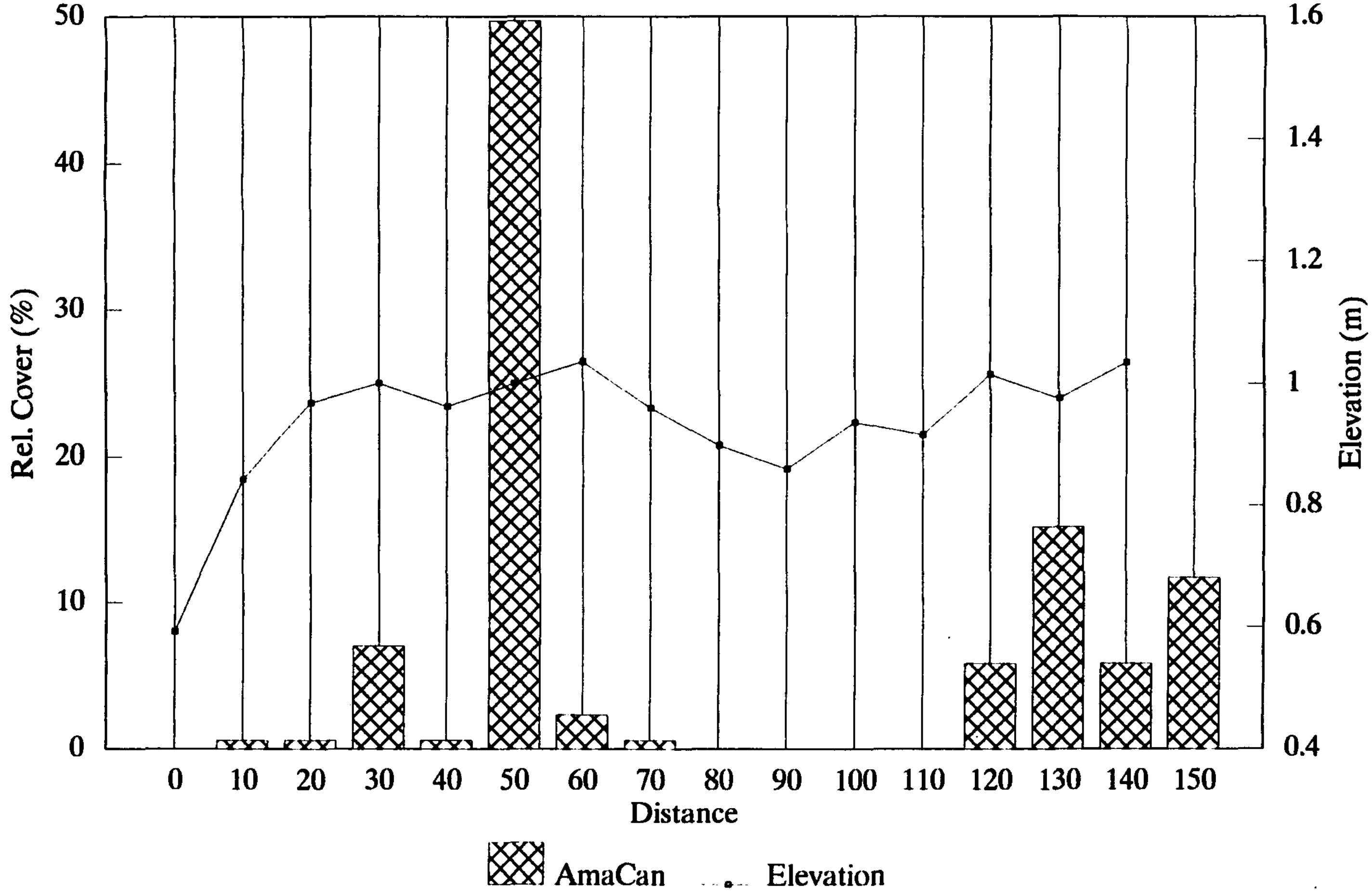


Note:1.Distance is measured in meters from the creek.
2.No elevation data available for this transect.

Figure 63. Distribution of AmaCan along transect 5.

DISTRIBUTION OF AmaCan

TRANSECT 5

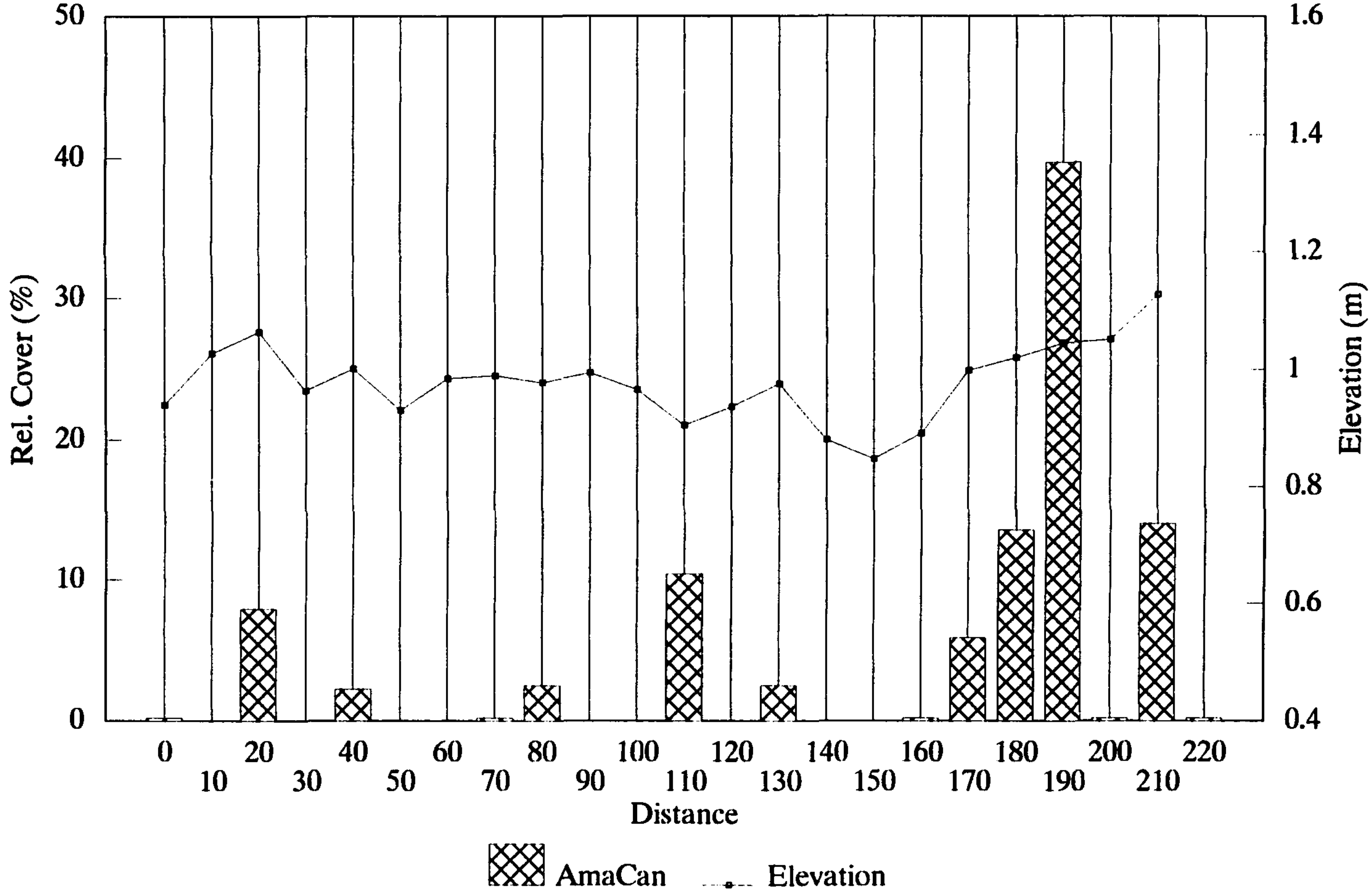


Note: Distance is measured in meters from the Pamunkey River.

Figure 64. Distribution of AmaCan along transect 6.

DISTRIBUTION OF AmaCan

TRANSECT 6

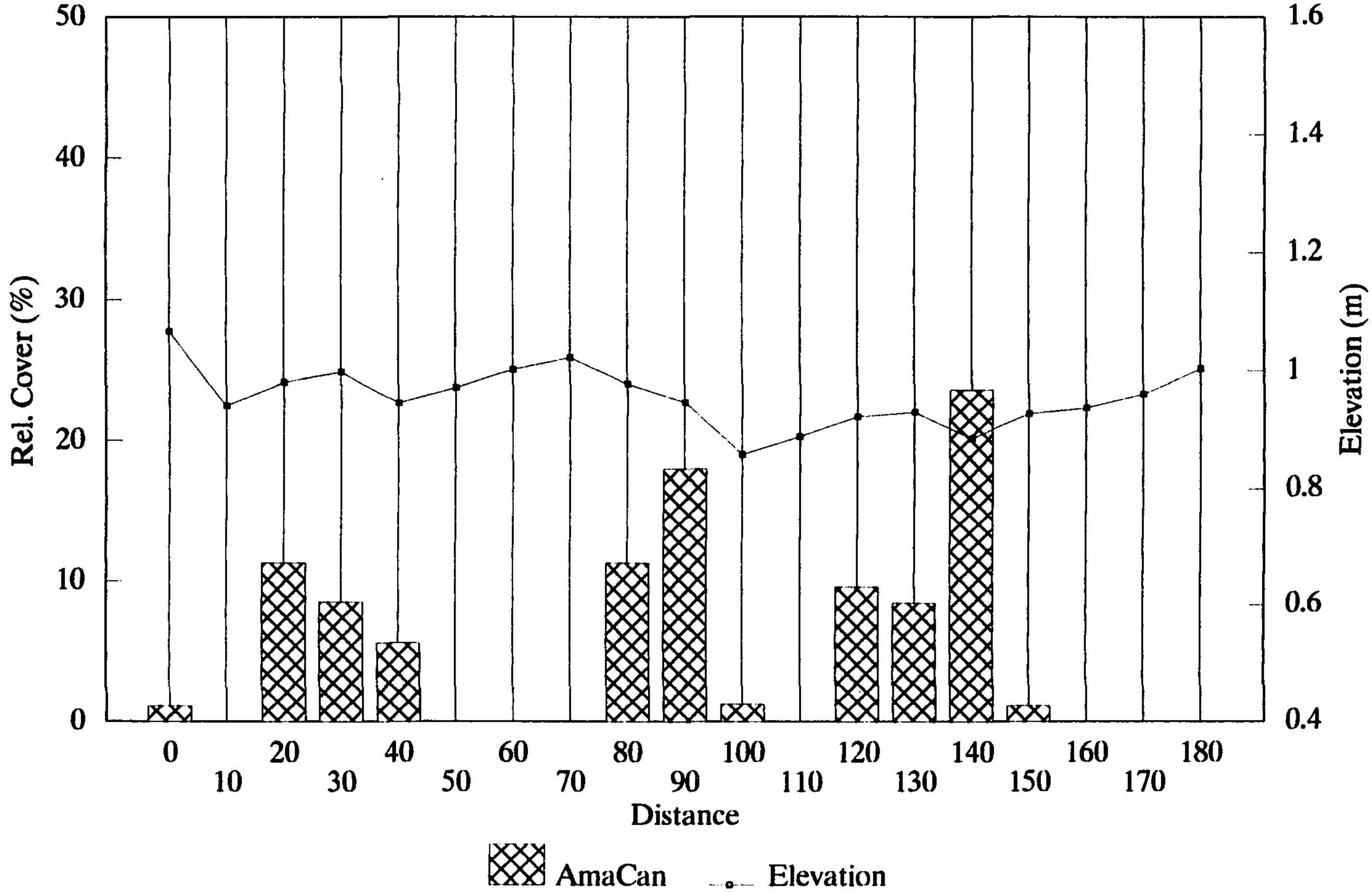


Note: Distance is measured in meters from the creek.

Figure 65. Distribution of AmaCan along transect 7.

DISTRIBUTION OF AmaCan

TRANSECT 7



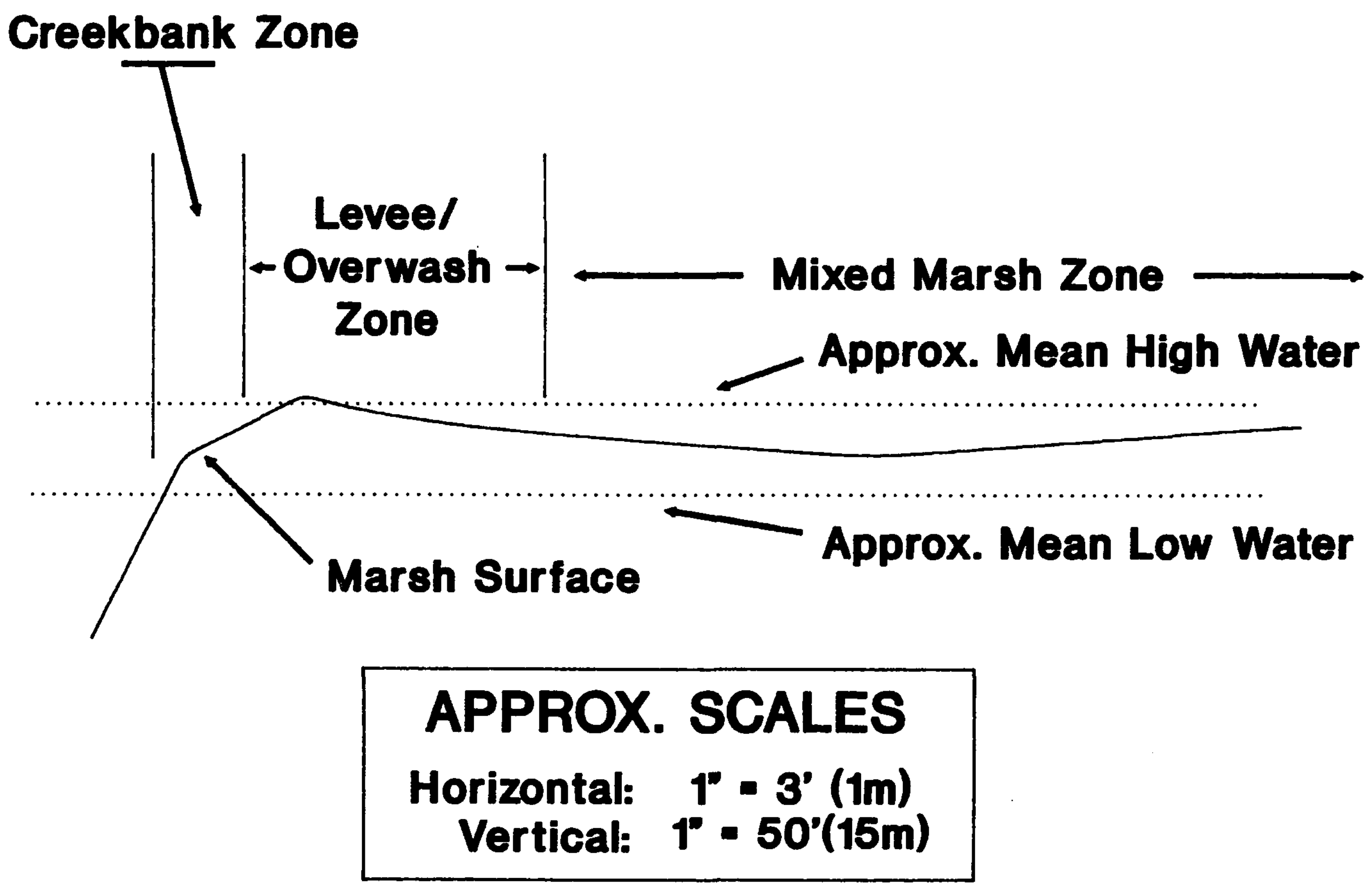
Note: Distance is measured in meters from the creek.

Table 7. Dominant species correlation matrix. Only coefficients significant at P >= 0.05 are shown. N = 985.

	AMACAN	BIDLAE	CARSTR	CARHYA	ECHWAL
PELVIR	0.0537	-	-0.1040	-0.0898	-0.0846
LEEORY	-	-	-0.1040	-	0.1071
ZIZAQU	-	0.2458	-0.0627	-0.0577	-0.0654
SPACYN	-	-0.1075	-0.1174	-0.0966	-
CARHYA	-	0.0572	-	NA	0.1024
POLPUN	-	0.0610	-0.0534	-	0.0511
BIDLAE	0.0819	NA	-	0.0572	0.0983
CARSTR	0.1259	-0.0464	NA	-	-0.0616
ECHWAL	-	0.0983	-0.0616	0.1024	NA
AMACAN	-	0.0819	0.1259	-	-

	LEEORY	PELVIR	POLPUN	SPACYN	ZIZAQU
PELVIR	-0.0713	NA	-	-	-0.0780
LEEORY	NA	-0.0713	-0.0590	0.1493	-
ZIZAQU	-	-0.0780	-0.1066	-0.1416	NA
SPACYN	0.1493	-	0.0866	NA	-0.1416
POLPUN	-0.0590	-	NA	0.0866	-0.1066

Figure 66. Generalized topographic profile for Sweet Hall Marsh.


Creekbank Zone
Levee/
Overwash
Zone
Mixed Marsh Zone
Approx. Mean High Water
Approx. Mean Low Water
Marsh Surface
APPROX. SCALES
Horizontal: 1" = 3' (1m)
Vertical: 1" = 50'(15m)

zone was defined by a sharp drop (approximately 80 to 90 degree angle) into the adjacent channels. Tidal flooding was semidiurnal and the zone was inundated approximately 30% of the time. The landward edge was delineated by a rapid transition to the levee-overwash zone and ended at approximately the mean high water mark. The lower limit of the vegetation in the zone was calculated to be mean low water. Vegetation was not persistent throughout the season.

Although several species were found in the zone, Peltandra virginica was dominant throughout the season. Other species included Echinochloa walteri, Polygonum punctatum, Rumex verticillatus, Scirpus americanus, and Spartina alterniflora. All of the species occurring in the creek zone were found in the other zones as well.

The second recognizable zone, the levee-overwash zone, was located landward of the creek zone. Tidal flooding of the levee-overwash zone was less frequent than that found on the creek zone. Inundation occurred approximately 26% of the time. The levee portion of the zone was represented by a ridge located landward of the creek zone and was present in all of the marsh adjacent to the Pamunkey River but only in approximately 1/2 of the marsh adjacent to the thoroughfare. It was more prominent in the eastern end of the thoroughfare and decreased westward. The overwash zone was located landward of the levee and varied in width from less than two meters to over twenty meters and was variable throughout the marsh. Due to the shape of the zone, the period of inundation of its waterward side should be longer than that of the landward side. Elevation of the marsh was highest on the crest of the levee. Overall, elevation of the levee-washover areas was the highest of the three zones.

In early spring the levee-overwash zone was dominated by P. virginica with Rumex verticillatus as a subdominant species. However, by late spring Spartina cynosuroides had become dominant and P. virginica, Phragmites australis and R. verticillatus subdominant. P. australis was more prominent in the overwash areas to the east and west ends of the marsh. Leersia oryzoides replaced R. verticillatus as a subdominant by mid-summer, the latter species having completed its seasonal growth cycle.

The third recognizable zone was designated the mixed marsh zone. It was the most complex of the three zones physically and vegetatively. Physically, the mixed marsh zone is partially protected from tidal activities by the higher levee-washover zone. However, breaks through the levee-washover zone did occur in the form of small creeks and muskrat burrows. The resulting effect is an area where inundation is dictated by the levee-overwash zone. Since the inundation model used in this study to calculate periodicity did not take the interdependence of zones into consideration, calculation of periodicity for the zone was not possible. The zone had little to no slope with the exception of areas adjacent to the small levee and overwash areas that had formed around small creeks that intermittently dissect the zone. Muskrat activity was common in the zone. A total of 114 dens were located on the site in 1986 (slightly less than two per hectare) (Hershner, personal communication). Many of the dens were located near creeks and near the overwash zones. However, no clear pattern was obvious. The impacted areas around dens ranged from 4 to 25 square meters in size and were nearly circular in shape. The vegetation in these "eatout" areas was grazed nearly to soil level and, at all times during the study was sparse. However, the vegetation found in eatout areas was similar in composition, albeit not coverage, to the surrounding areas.

Overall, the vegetation of the mixed marsh area was heterogeneous and contained a diverse array of plant species. In early spring, *Peltandra virginica* was dominant throughout the zone with several small areas (less than 500 square meters) dominated by *Carex stricta*. By July, it was evident that a large number of the *P. virginica* dominated stands had become or would soon become dominated by *Leersia oryzoides* or *Zizania aquatica*. The *C. stricta* areas, on the other hand, generally remained dominated by the same species. However, a number of codominant species such as *Bidens* spp., *Hibiscus moscheutos*, *Cicuta maculata*, and *Osmunda regalis* (which became dominant over *C. stricta* in several small cases) were quite evident. Throughout the season, some areas remained dominated by *P. virginica*. Areal coverage for all species found in these areas was much lower than that measured for the creek zone area (seasonally dominated by P. virginica).

II. VEGETATION CHANGES

Comparison with Previous Study

IMPORTANCE VALUES: Importance values (IV) from Doumlele's 1976 study are available for only the ten species with the highest values. The ten species with the highest IV for each study are compared in Table 8 and 9. The two species with the highest values (Peltandra virginica and Leersia oryzoides) are the same from both studies (Tables 8 and 9). However, only two other species that appeared on Doumlele's list (Polygonum punctatum and Carex stricta) were ranked within the ten highest IV in this study (Table R4). Three of the four that occurred on both lists are perennials (P. virginica, L. oryzoides and C. stricta) and one (Polygonum punctatum) an annual. Of the six species with the highest values in this study that do not appear on Doumlele's list, two are perennial (Carex hyalinolepis and Spartina cynosuroides) and four are annuals (Amaranthus cannabinus, Bidens laevis, Echinochloa walteri, and Zizania aquatica). The six species from Doumlele's list which had lower values in this study included three perennials (Eleocharis quadrangulata, Hibiscus moscheutos, and Pontederia cordata) and three annuals (Aneilema keisak, Impatiens capensis, and Polygonum punctatum).

Table 8. Comparison of species importance values (IV) from Doumlele's study (Doumlele, 1976) and this study. Only the ten species with the highest ten values were given.

SPECIES	1976 RANK	1976 MEAN	1987 RANK	1987 MEAN
PelVir	1	82.40	1	86.36
LeeOry	2	77.78	2	58.70
PolPun	3	31.85	6	16.58
PonCor	4	14.93	11	4.19
CarStr	5	14.62	8	6.17
ImpCap	6	13.87	36	0.21
AneKei	7	13.42	14	2.83
PolAri	8	9.86	13	3.25
EleQua	9	4.34	17	2.22
HibMos	10	3.66	23	0.88

Table 9. Comparison of species importance values (IV) from this study and Doumlele's study (Doumlele, 1976). Only the ten species with the highest ten values are given. NA=not available.

SPECIES	1987 RANK	1987 MEAN	1976 RANK	1976 MEAN
PelVir	1	86.36	1	82.40
LeeOry	2	58.70	2	77.78
ZizAqu	3	30.36	NA	NA
SpaCyn	4	26.19	NA	NA
CarHya	5	21.46	NA	NA
PolPun	6	16.65	6	16.58
BidLae	7	9.52	NA	NA
CarStr	8	6.17	5	14.62
EchWal	9	5.80	NA	NA
AmaCan	10	4.61	NA	NA

The species that dropped from the list were P. cordata (4th to 11th), I. capensis (6th to 36th), A. keisak (7th to 14th), P. arifolium (8th to 13th), E. quadrangulata (9th to 17th), and H. moscheutos (10th to 23rd).

DIVERSITY: There was no significant difference between the seasonal measures of diversity index, species richness and species evenness for the two studies (P<0.05) (Figure 67). However, there was a significant difference between the two studies in the ten species that had the highest importance values (P<0.05). Also, a similarity index for the two was low (Jaccard's Index = 54.6%). Therefore, although overall complex diversity measures were not significantly different between studies, the species used to calculate those parameters were different.

Interpretation of Aerial Photography

Black and white aerial photographs of Sweet Hall Marsh were available for the years 1938, 1953, 1960, 1969, and 1976 as well as a color infra-red (CIR) 1976 photo. The scale for each photo was 1:4800. All but the 1938 photo were rectified.

The three zones described above, the creek, levee and overwash, and mixed marsh zone, were identifiable in the aerial photographs by texture and/or color. However, the border between the overwash area and mixed marsh zone was obscure and difficult to delineate. A fourth and nonvegetated zone became evident in the 1960 photos.

The border of the creek zone was easily recognizable regardless of tide levels at the time that the photos were taken. The waterward edge was delimited by a line of light brown color channelward and dark brown to black landward. The zone could further be divided into two subzones: vegetated and non-vegetated. The former was landward and easily delineated from the latter by its darker color and rougher texture. The landward limit of the vegetated subzone (thus, also the limit of the creek zone) was delineated by the very rough texture and, with exception of the 1938 photo, lighter color of the levee/overwash zones signature.

Geographic Information System analysis of the zones are presented in reverse chronology (most recent to oldest) in Figures 67 to 71 and Table 10. Initial attempts at comparing the photographs were poor. Total size of the area under investigation varied from a low of 44.4 hectares in 1976 to 46.1 hectares in 1953 (Table 11), a difference of 1.7 hectares (3.6% of the 1953 area). In many cases the variation in total size was larger than the changes that were calculated for the vegetation associations (Table 12). Therefore, a relative size (vegetation assemblage divided by total area) was used to calculate the percent of each assemblage from each photograph. The change in each assemblage could then be calculated as the difference of its percentage from one photograph to the next. To use this process it was assumed that the variation of the total size was due to flight elevation

Figure 67. 1976 delineation of the dominant vegetation associations of Sweet Hall Marsh. Associations determined by photographic signature.

UPPER LIMITS SWEET HALL MARSH
PAMUNKEY RIVER, VA.
1976

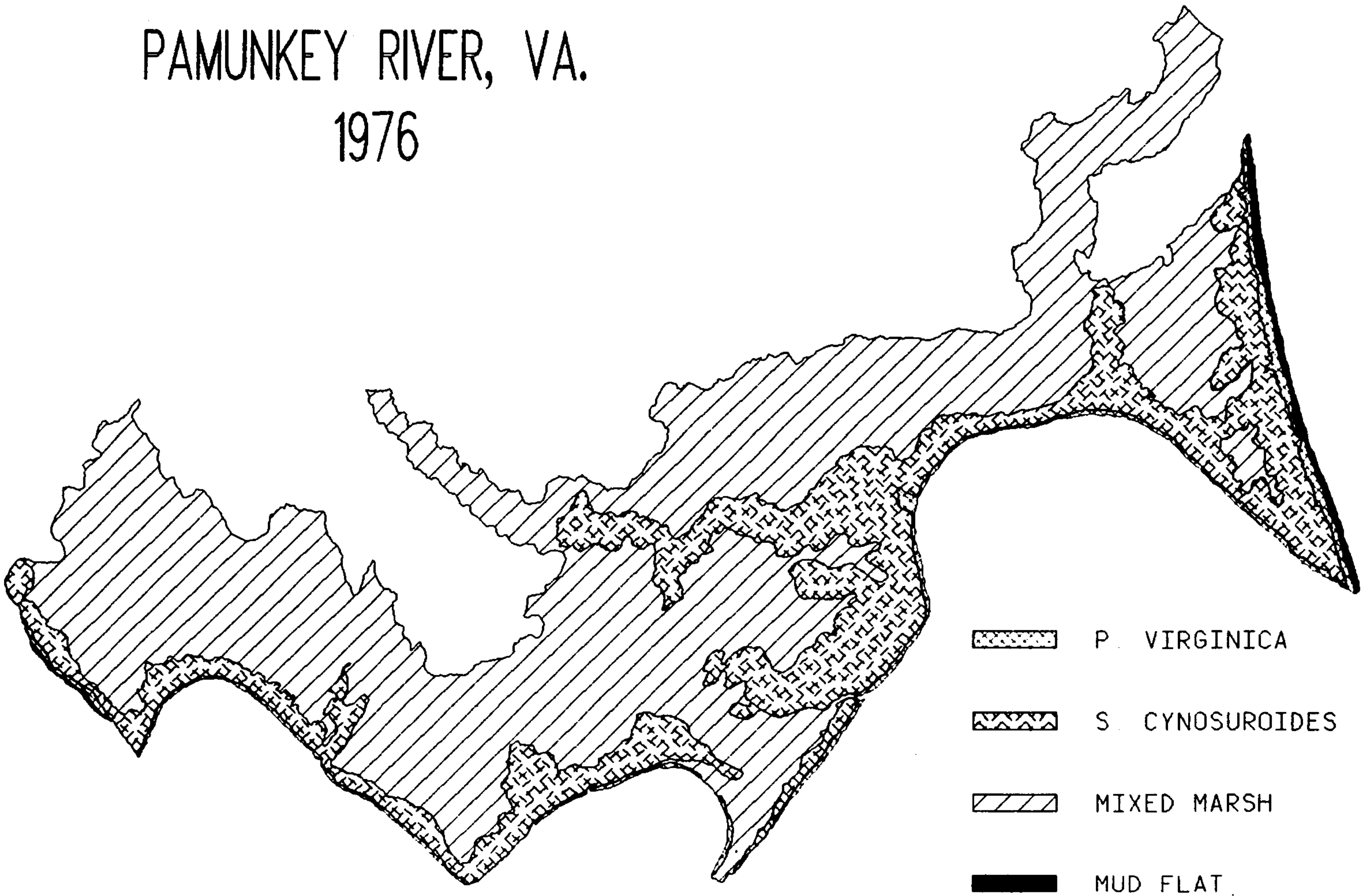


Figure 68. 1969 delineation of the dominant vegetation associations of Sweet Hall Marsh. Associations determined by photographic signature.

UPPER LIMITS SWEET HALL MARSH
PAMUNKEY RIVER, VA.
1969

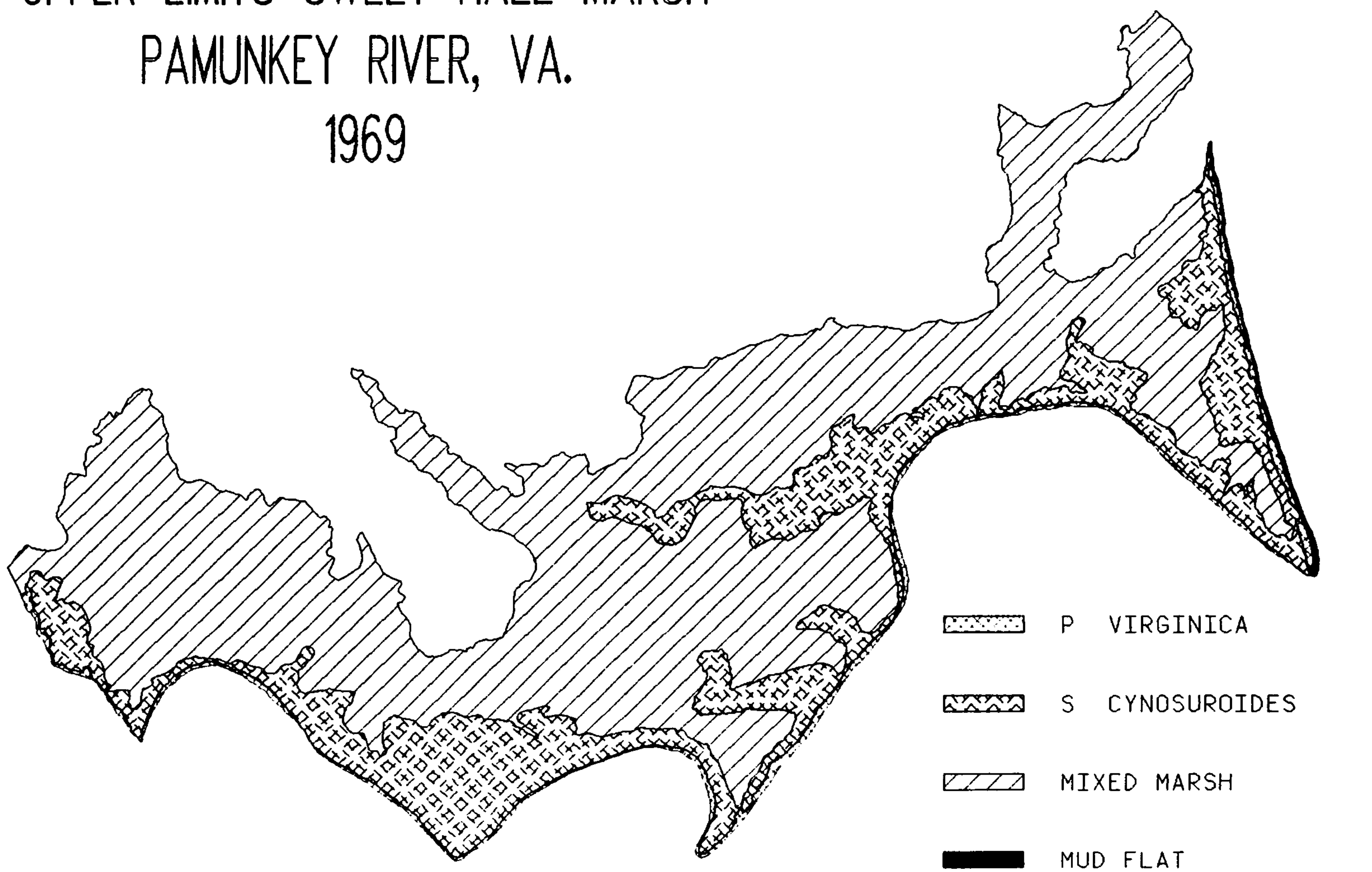


Figure 69. 1960 delineation of the dominant vegetation associations of Sweet Hall Marsh. Associations determined by photographic signature.

UPPER LIMITS SWEET HALL MARSH
PAMUNKEY RIVER, VA.
1960

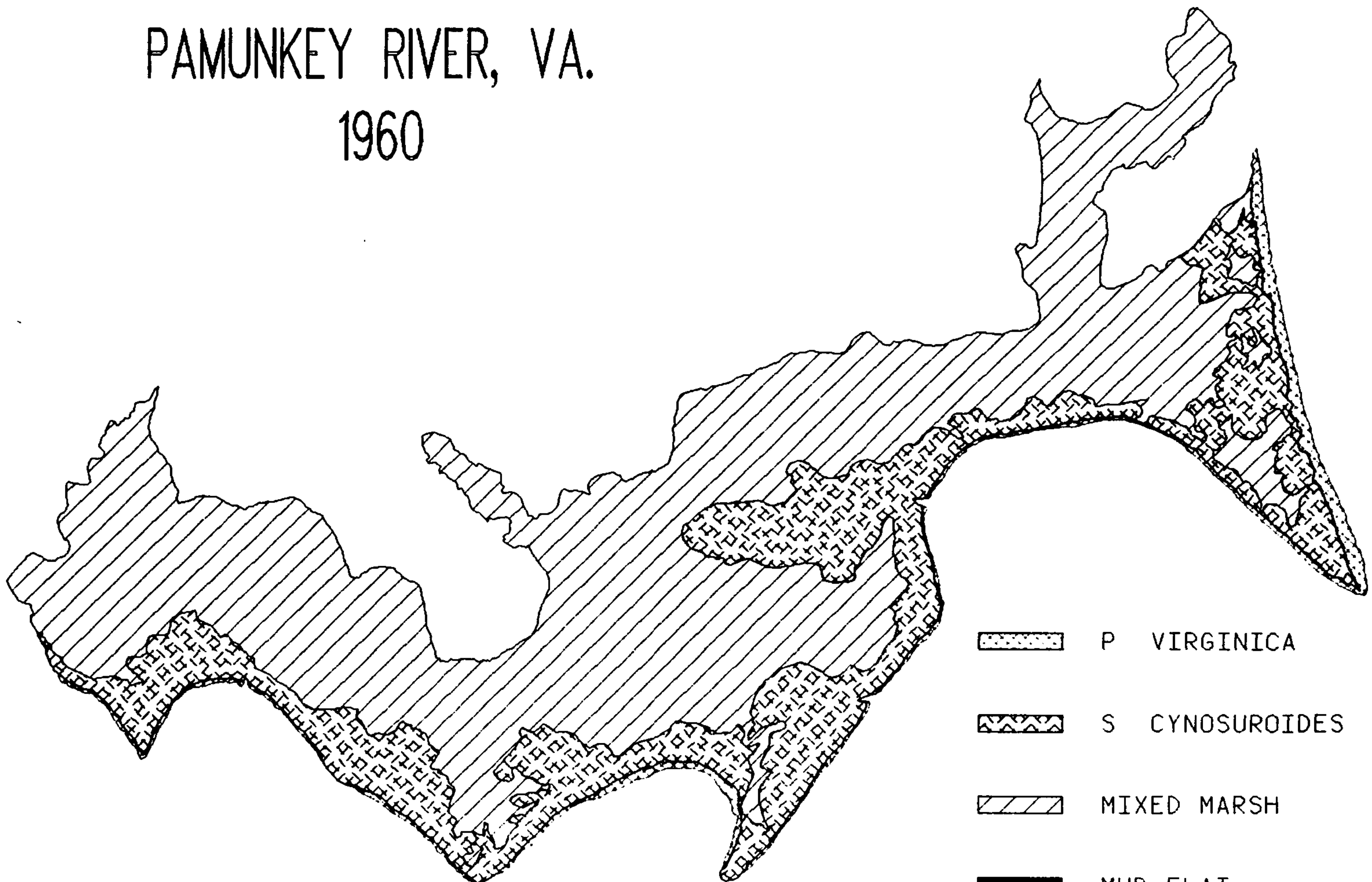


Figure 70. 1953 delineation of the dominant vegetation associations of Sweet Hall Marsh. Associations determined by photographic signature.

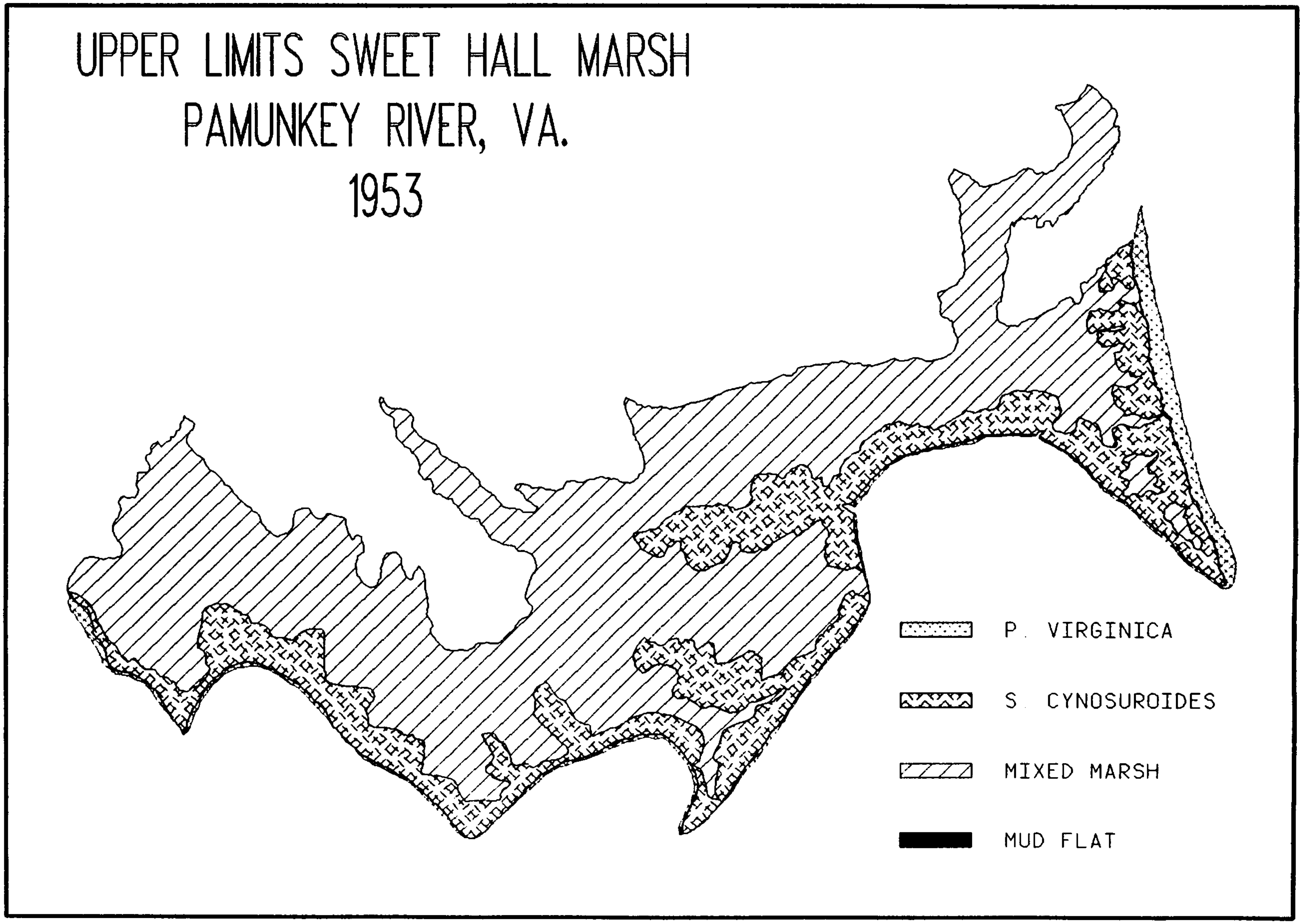

UPPER LIMITS SWEET HALL MARSH
PAMUNKEY RIVER, VA.
1953
P. VIRGINICA
S. CYNOSUROIDES
MIXED MARSH
MUD FLAT

Figure 71. 1937 delineation of the dominant vegetation associations of Sweet Hall Marsh. Associations determined by photographic signature.

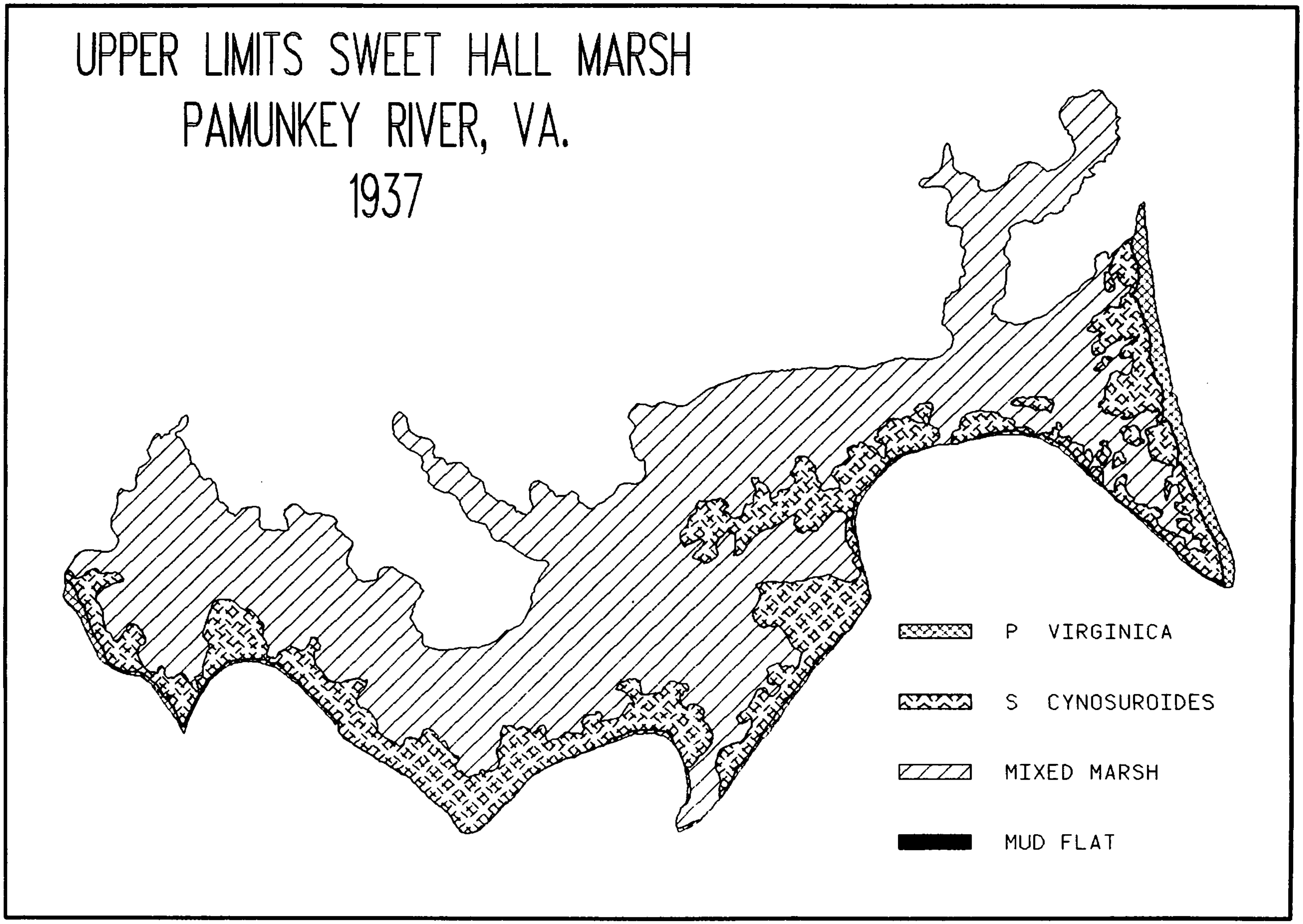

UPPER LIMITS SWEET HALL MARSH
PAMUNKEY RIVER, VA.
1937
P VIRGINICA
S CYNOSUROIDES
MIXED MARSH
MUD FLAT

Table 10. Size (in square meters) of vegetation associations/topographic zones of Sweet Hall Marsh.

ZONE	SUBZONE	DATE OF PHOTOGRAPHS 1937	1953	1960	1969	1976
Creekbank	Mudflat	0	0	0	1642	3637
	PelVir	15104	16761	14452	11101	11281
Levee/Overwash		107455	121544	122643	111660	116916
Mixed Marsh		327739	322056	311094	333526	311896
Total Area		450301	460512	448340	457931	443760

Table 11. Size change (in square meters) of topographic/vegetation zones of Sweet Hall Marsh.

ZONE	SUBZONE	DATE OF PHOTOGRAPHS 37-53	53-60	60-69	69-76	37-76
Creekbank	Mudflat	0	0	+1642	+1995	+1995
	PelVir	+1657	-2309	-3351	+180	-3823
Levee/Overwash		+14089	+1099	-10983	+5256	+9461
Mixed Marsh		-5683	-10962	+22432	-21630	-15630
Total Area		+10211	-12172	+9591	-14171	-6541

Table 12. Temporal change in relative size of vegetation assemblages (zones) of Sweet Hall Marsh. Changes were calculated as percent of total area.

ZONE	SUBZONE	DATE OF PHOTOGRAPHS 37-53	53-60	60-69	69-76	37-76
Creekbank	Mudflat	0	0	0	0.46	0.82
	PelVir	0.29	-0.42	-0.80	0.12	-0.81
Levee/Overwash		2.53	0.96	-2.97	1.97	2.49
Mixed Marsh		-2.85	-0.59	3.49	-2.55	-2.50

variation alone and not cartography or digitizing error nor to tide height. The temporal changes (in relative percentage) are given in Table 12.

III. ENVIRONMENTAL PARAMETERS

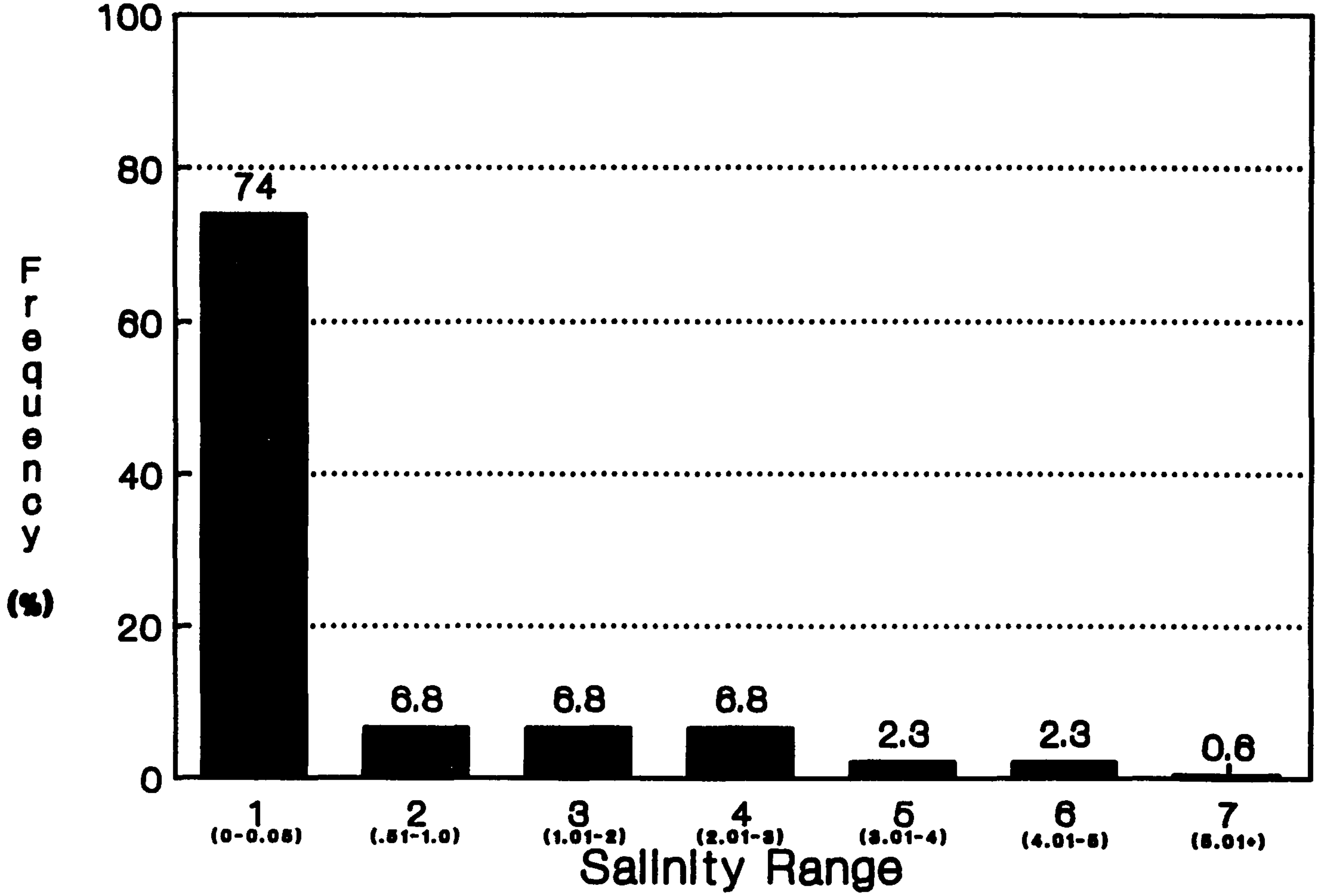
Salinity

The data used for this analysis were collected in 1974 through 1986 during a York River slack water study conducted by the Virginia Institute of Marine Sciences. Only the data from station 22.73, located to the south of Sweet Hall Marsh, and in the top one meter of the water's surface, were used.

For analysis purposes, salinity was broken into seven (7) ranges (Figure 72) and the frequency distribution calculated for each range. Range 1 was 0 to 0.50 ppt (parts per thousands) and represents the range of salinities normally expected in a tidal freshwater marsh (Odum et al., 1984). The next range (2) was 0.51 to 1.0 ppt and can be considered the transition range between oligohaline and tidal fresh water systems. Ranges 3,4,5, and 6 each represented one ppt increase over the preceding range. Range 7 represented salinities greater than 5 ppt. The mean salinity for the data set was 0.45 ppt. The highest salinity observed was 7.5 and the lowest 0.0. The system was dominated by salinities of 0.05 (ppt) or less nearly three quarters of the time (74%). The next

Figure 72. 12 year mean salinity frequency distribution of the Pamunkey River at kilometer 22.72 (south end of Sweet Hall Marsh). Calculated from the top one meter of the water column samples.

SALINITY FREQUENCY DISTRIBUTION



N=176, 1974-1986

three ranges were equally represented (6.8%). A monthly breakdown of the data shows that low salinities dominate the growing season with an increase late in the growing season and fall (Figure 73). A breakdown by yearly mean salinity with a best fit regression line shows an increasing trend in salinity in the Sweet Hall Marsh area (P=0.05) (Figure 74).

Elevation

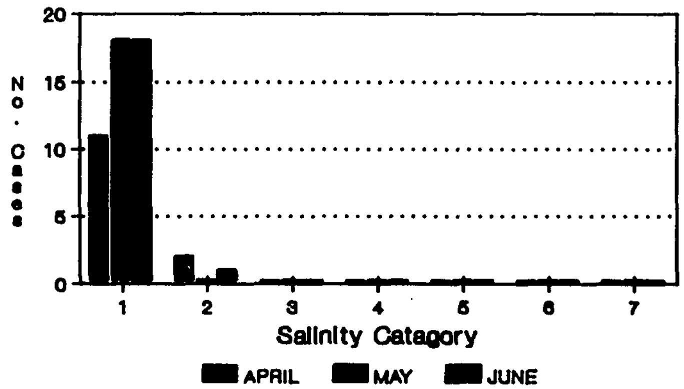
The elevation of the systematic plots was taken on five of the seven transects (transects 1,2,5,6, and 7).

Using the elevations and species occurrence from each plot of the five transects, the elevation distribution of each species was determined (Table 13). *Peltandra virginica* had the largest distribution range and *Spartina cynosuroides* and *Carex stricta* the narrowest (Table 13, Figure 75).

The relative frequency distribution for three perennials (data not available for *Carex* spp.) and five annuals from the list are shown in Figure 76 and 77, respectively. The perennials were skewed to the right (higher elevations) on what resembles a normal curve while the annuals had a scattered distribution that were, on a mean of annuals vs. perennials, skewed more to the left (lower elevations) of the perennial curve (Figure 78). Therefore, as a whole, perennials are more often found in the higher elevation of the marsh than annuals. Bar charts for individual species are given in Appendix II.

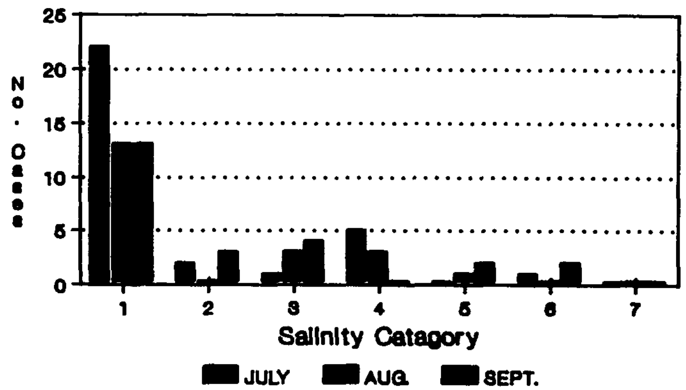
Figure 73. Seasonal salinity of Sweet Hall Marsh.

Early Growing Season



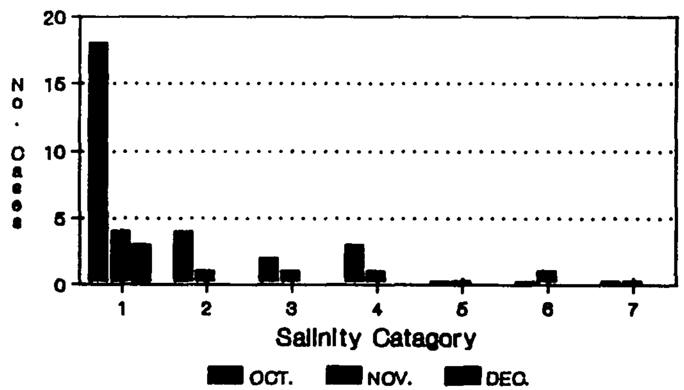
N=60

Late Growing Season



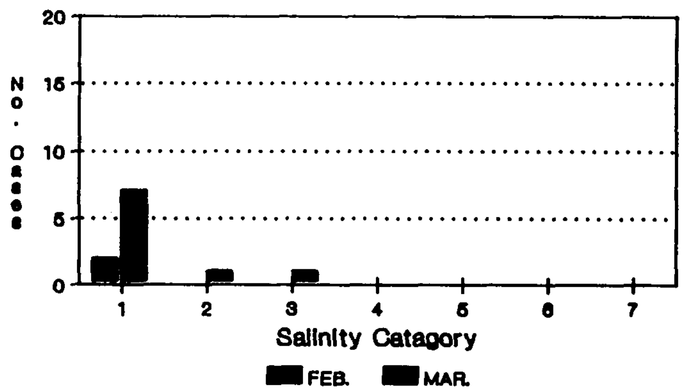
N=75

Fall Season



N=68

Winter Season



N=11

Figure 74. Best fit regression of mean salinity data for Sweet Hall Marsh (P=0.05).

SWEET HALL MARSH SALINITY

Yearly Means (1971-1986)

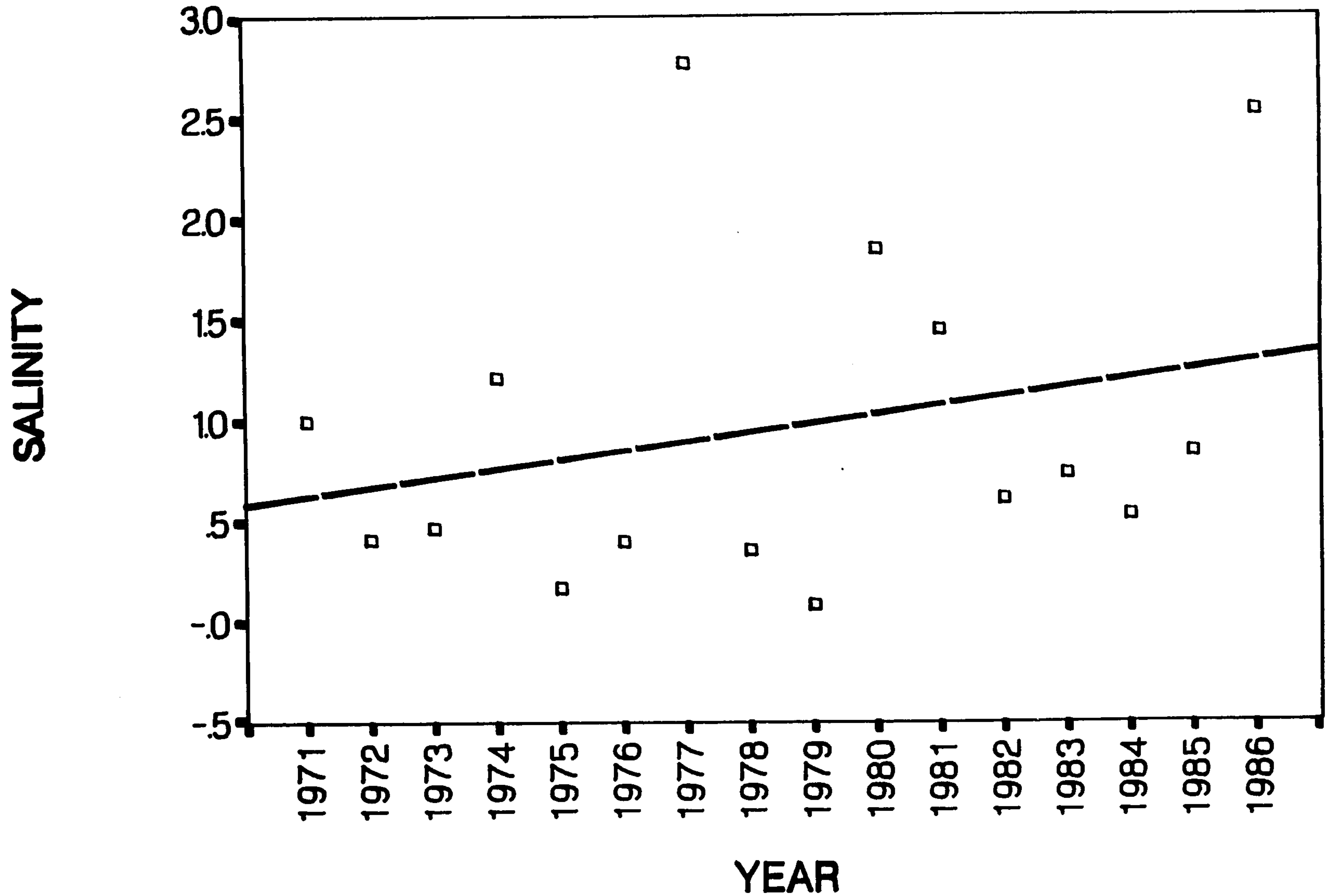


Table 13. Elevation parameters of dominant macrophytes of Sweet Hall Marsh. Measurements are in meters. N=number of samples.

SPECIES	N	MEAN	SD	RANGE
PelVir	94	0.962	0.081	0.554
LeeOry	76	0.975	0.065	0.385
ZizAqu	47	0.948	0.057	0.279
SpaCyn	33	1.001	0.048	0.249
CarHya	6	1.056	0.079	0.187
PolPun	49	0.969	0.070	0.300
BidLae	28	0.952	0.048	0.181
CarStr	9	0.960	0.035	0.093
EchWal	27	0.955	0.076	0.372
AmaCan	33	0.975	0.068	0.291

Figure 75. Elevation ranges of the dominant macrophytes of Sweet Hall Marsh.

```
           0.000     0.200     0.400     0.600     0.800
            |    .    |    .    |    .    |    .    |
PelVir         *****************************

LeeOry                  ********************

ZizAqu                  **************

SpaCyn                      *************

CarHya                               *******

PolPun                      ****************

BidLae                        **********

CarStr                           ***

EchWal                   *******************

AmaCan                       ***************
```

Figure 76. Elevation distribution of dominant annual macrophytes of Sweet Hall Marsh.

RELATIVE FREQUENCY DISTRIBUTION

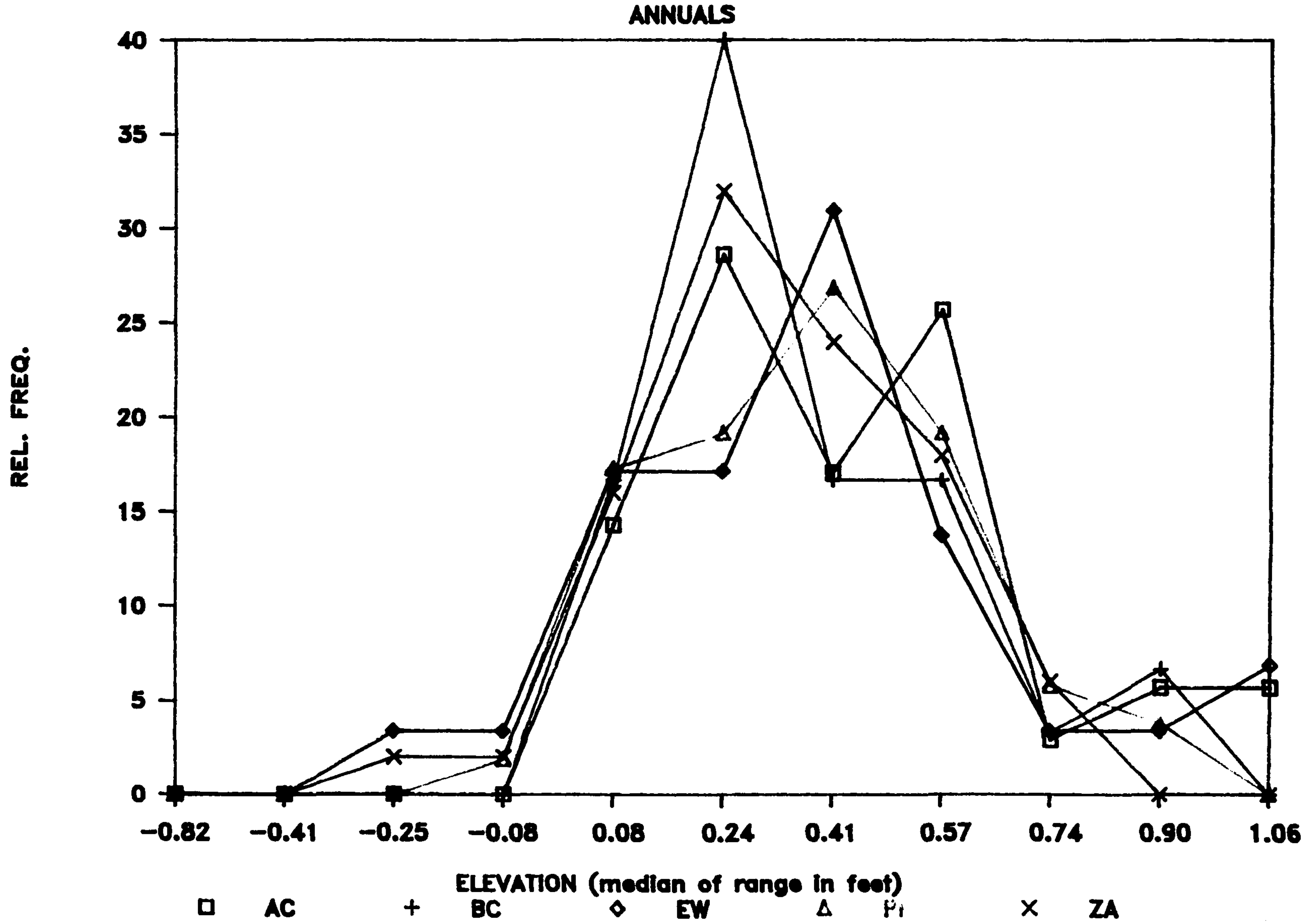


Figure 77. Elevation distribution of dominant perennial macrophytes of Sweet Hall Marsh.

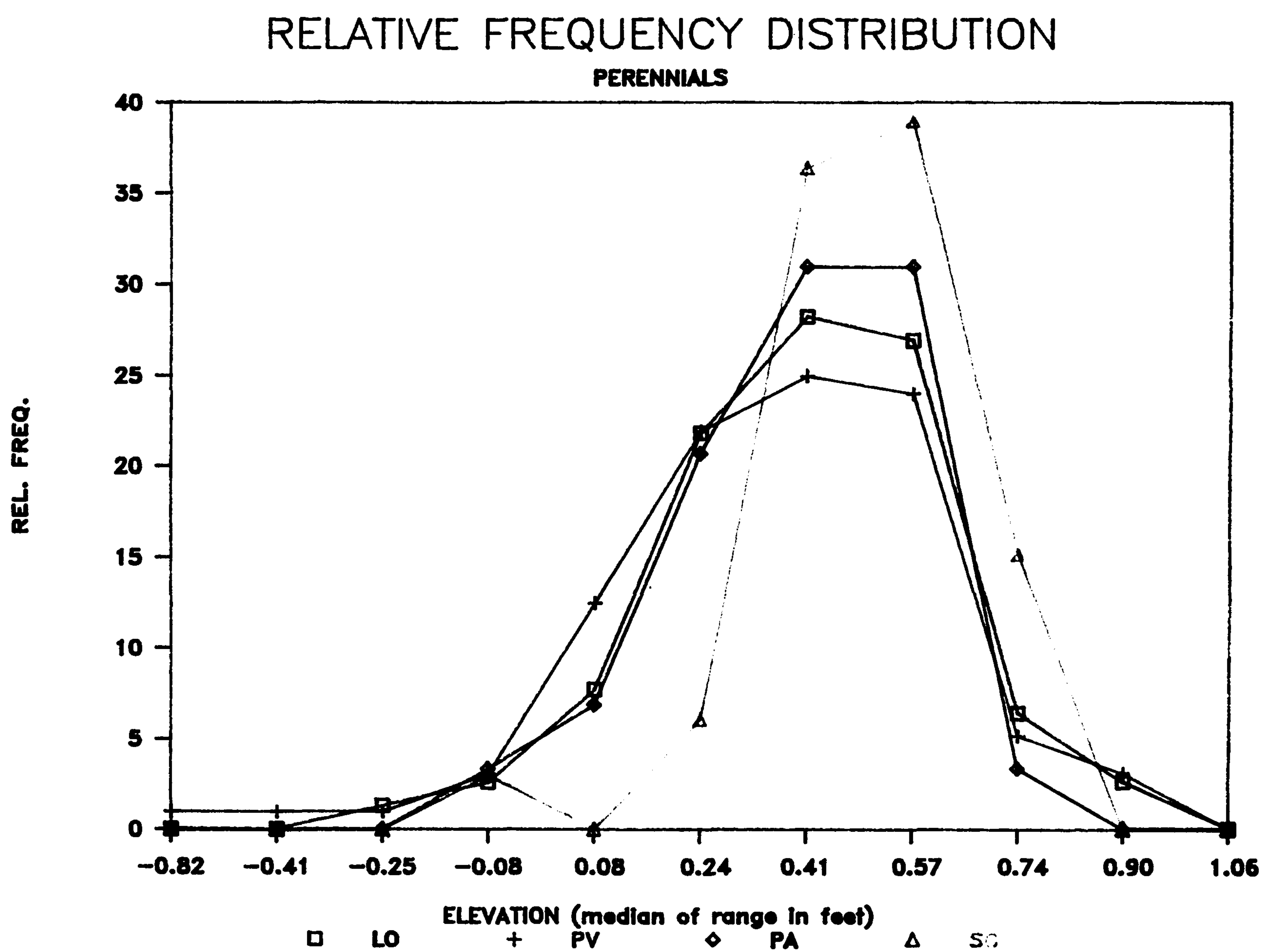
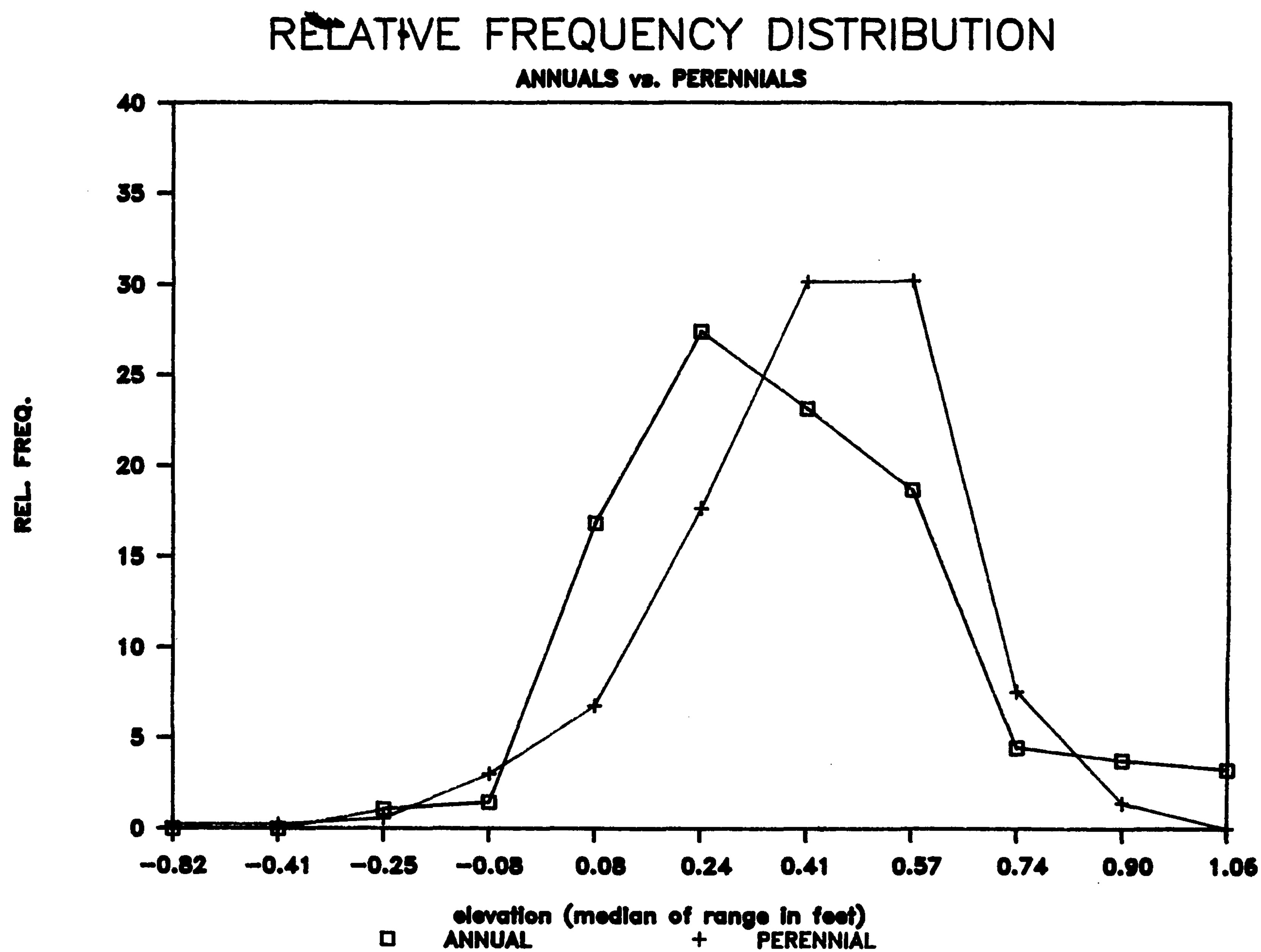

RELATIVE FREQUENCY DISTRIBUTION
PERENNIALS
REL. FREQ.
40
35
30
25
20
15
10
5
0
−0.82
−0.41
−0.25
−0.08
0.08
0.24
0.41
0.57
0.74
0.90
1.06
ELEVATION (median of range in feet)
LO
PV
PA

Figure 78. Mean elevation distribution of annual and perennial macrophytes of Sweet Hall Marsh.


RELATIVE FREQUENCY DISTRIBUTION
ANNUALS vs. PERENNIALS
REL. FREQ.
40
35
30
25
20
15
10
5
0
-0.82
-0.41
-0.25
-0.08
0.08
0.24
0.41
0.57
0.74
0.90
1.06
elevation (median of range in feet)
ANNUAL
PERENNIAL

Only two species, Leersia oryzoides and Spartina cynosuroides, were significantly correlated with elevation ($P<0.05$). Both correlations had positive coefficients (0.3461 and 0.2658, respectively).

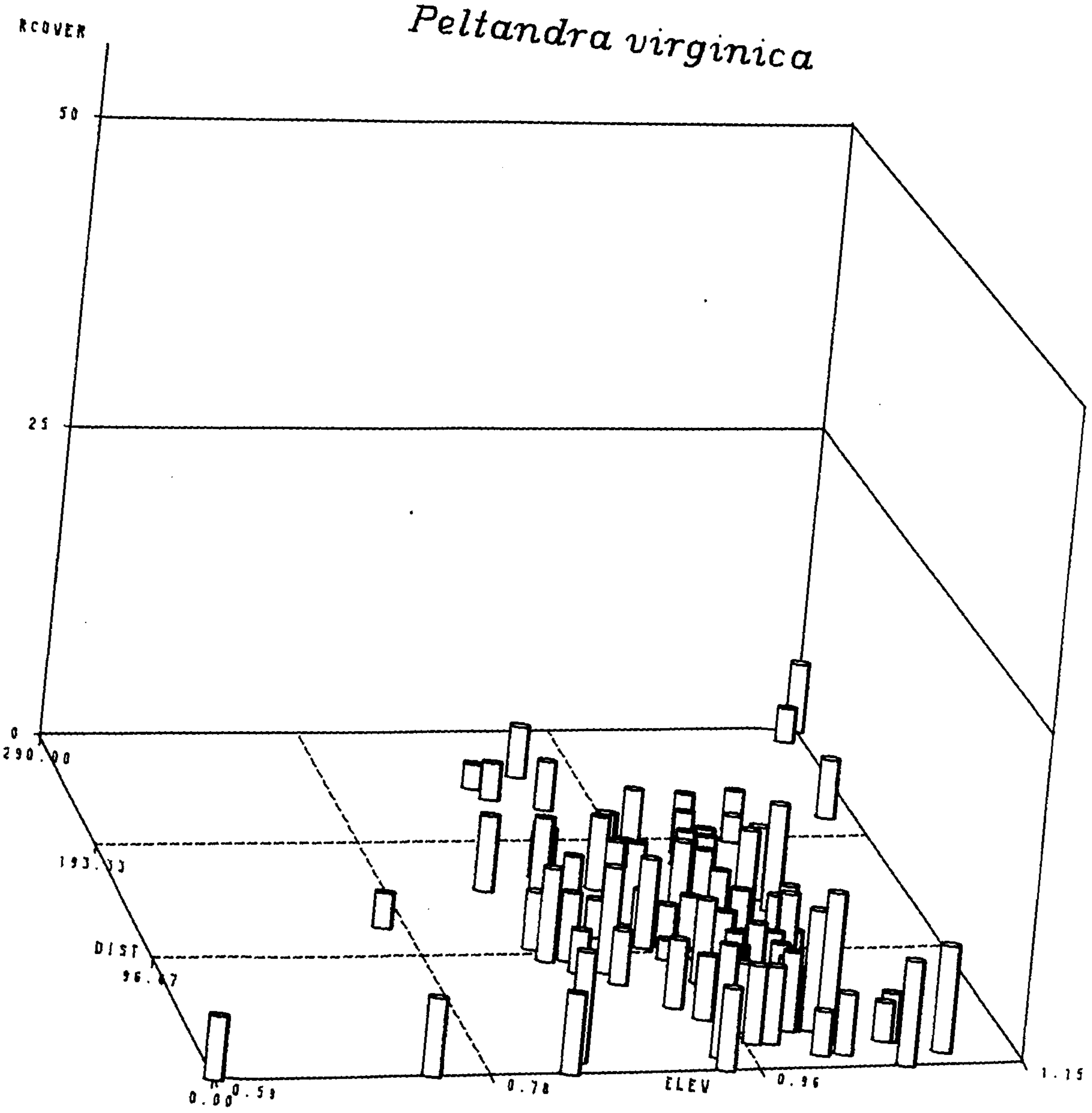
The relationship of elevation and distance of the sampling quadrat from a main creek is shown for the first four species using three dimensional graphics with elevation and distance as the x and y axis, respectively, and mean annual relative cover for the z axis (Figures 79a to 82b). Figures 79a through 82a are rotated to show placement of the species along the distance gradient (y axis) and Figures 79b through 82b along the elevation gradient (x axis). Of particular note is the evenness in distribution of Peltandra virginica throughout its range (Figures 79a and b) and the clustered affect of Spartina cynosuroides on both gradients (Figures 82a and b). Only P. virginica showed an affinity for the creek bank zone (Figure 79). It is also possible to see that Zizania aquatica had little affinity for the levee or creek bank zone of the marsh (Figure 81b).

Tides and Inundation Periodicity

A tide calendar was produced for Sweet Hall Marsh in order to calculate inundation periodicity for individual species (i.e. the

Figure 79a. Relative cover of PelVir along the elevation and distance gradient of Sweet Hall Marsh. View along the elevation gradient is emphasized.

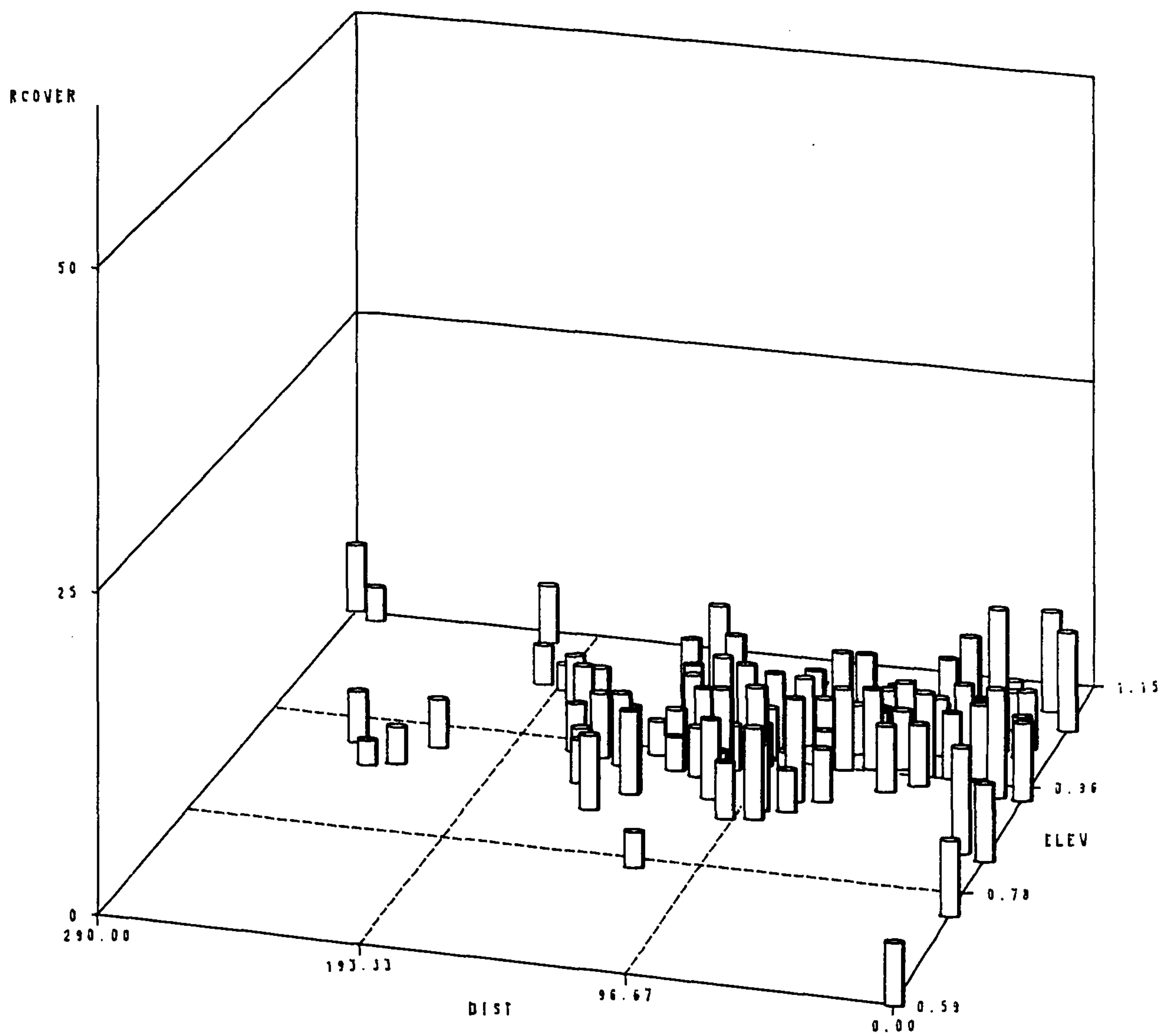
Peltandra virginica



DIST: Distance in meters from the creek.
ELEV: Elevation in meters.

Figure 79b. Relative cover of PelVir along the elevation and distance gradient of Sweet Hall Marsh. View along the distance gradient is emphasized.

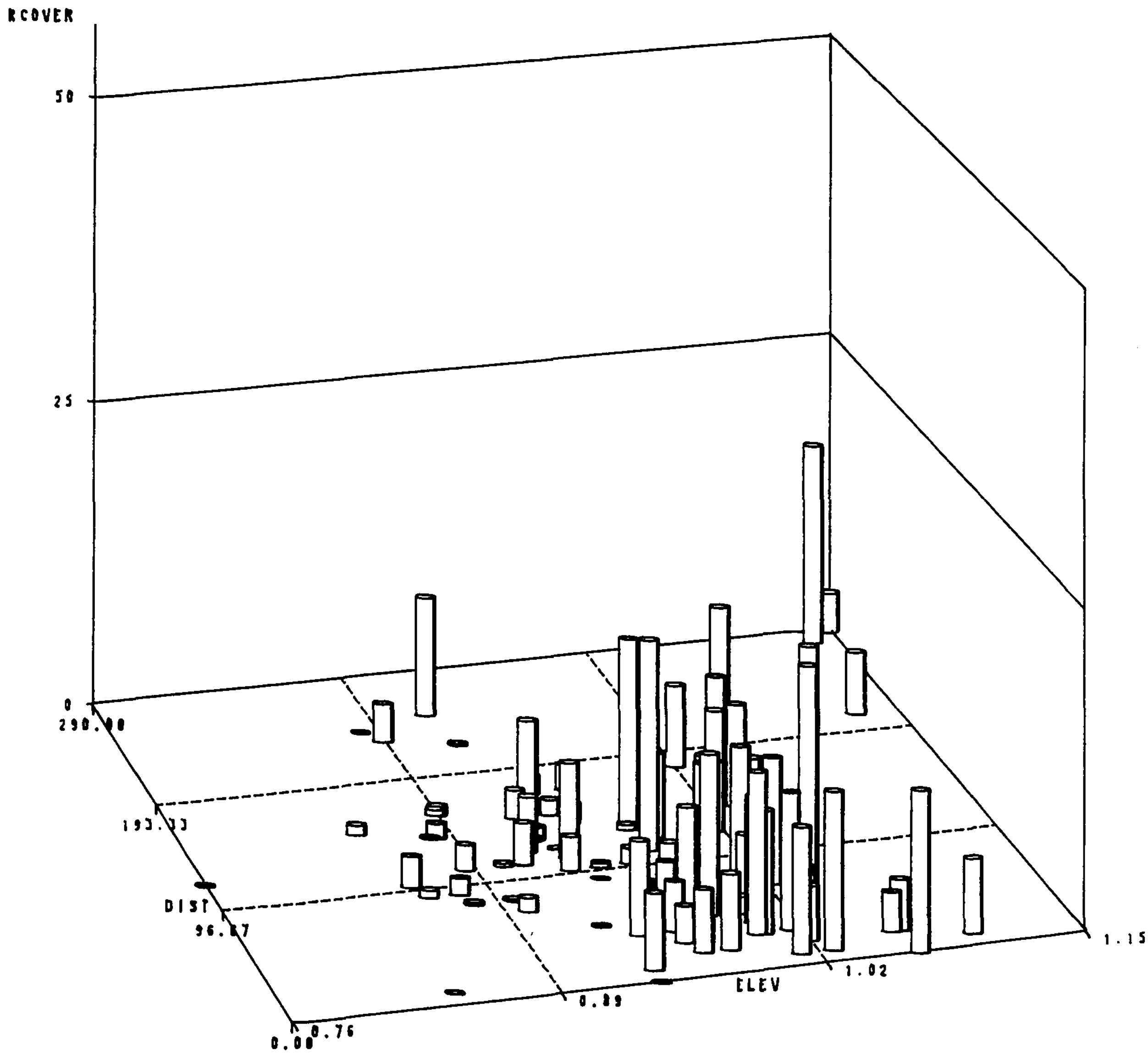
Peltandra virginica



DIST: Distance in meters from the creek.
ELEV: Elevation in meters.

Figure 80a. Relative cover of LeeOry along the elevation and distance gradient of Sweet Hall Marsh. View along the elevation gradient is emphasized.

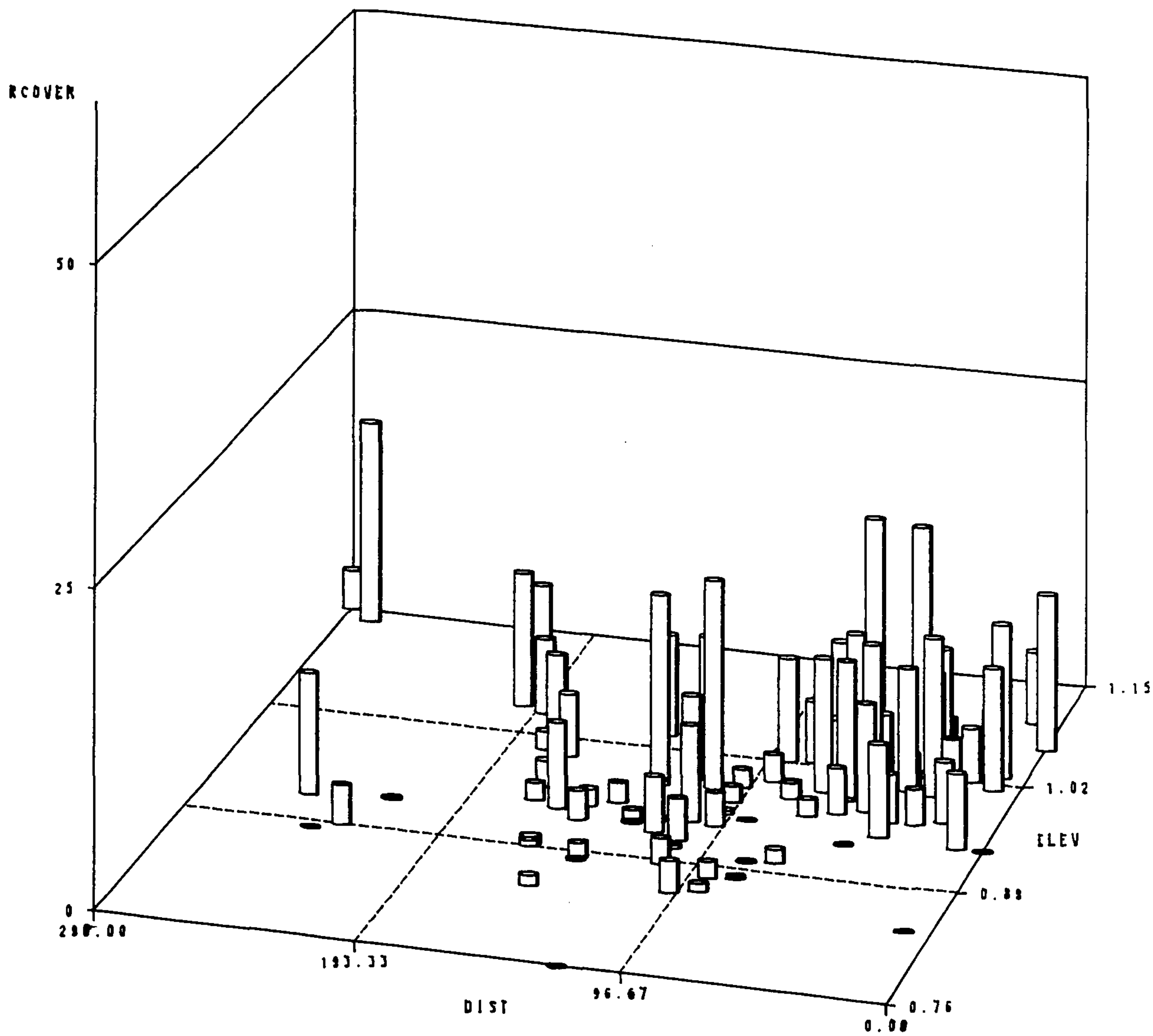
Leersia oryzoides



DIST: Distance in meters from the creek.
ELEV: Elevation in meters.

Figure 80b. Relative cover of LeeOry along the elevation and distance gradient of Sweet Hall Marsh. View along the distance gradient is emphasized.

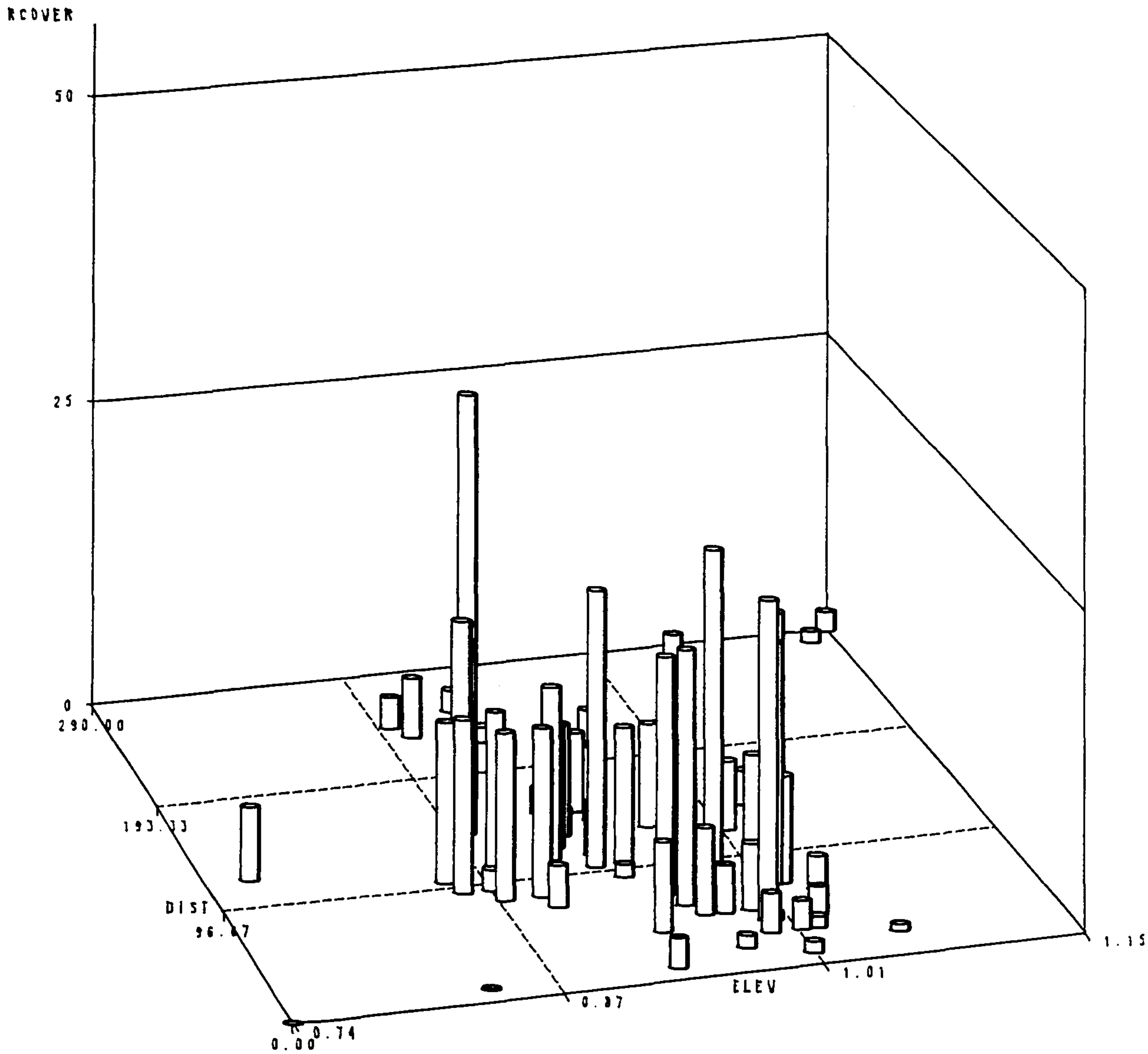
Leersia oryzoides



DIST: Distance in meters from the creek.
ELEV: Elevation in meters.

Figure 81a. Relative cover of ZizAqu along the elevation and distance gradient of Sweet Hall Marsh. View along the elevation gradient is emphasized.

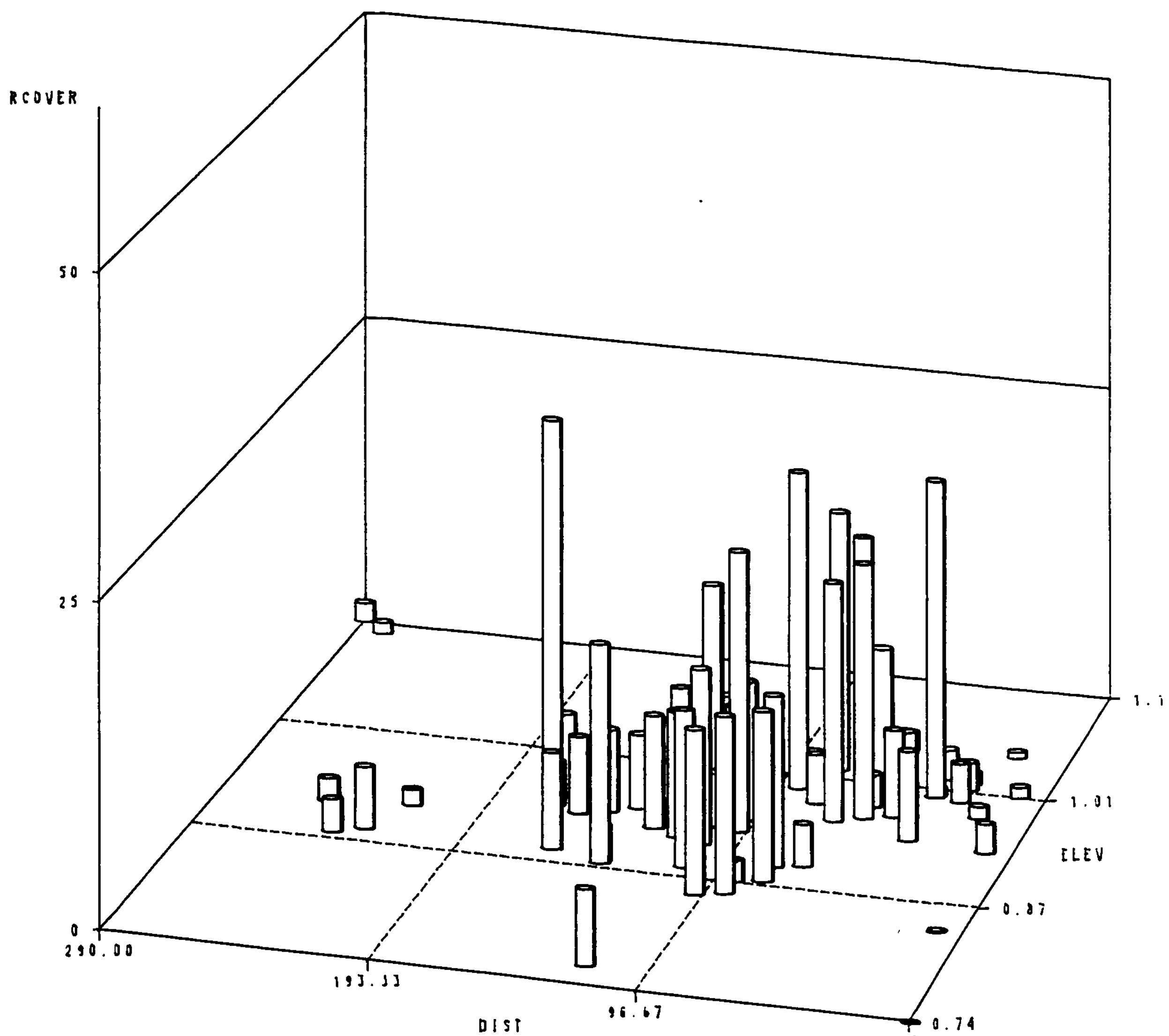
Zizania aquatica



DIST: Distance in meters from the creek.
ELEV: Elevation in meters.

Figure 81b. Relative cover of ZizAqu along the elevation and distance gradient of Sweet Hall Marsh. View along the distance gradient is emphasized.

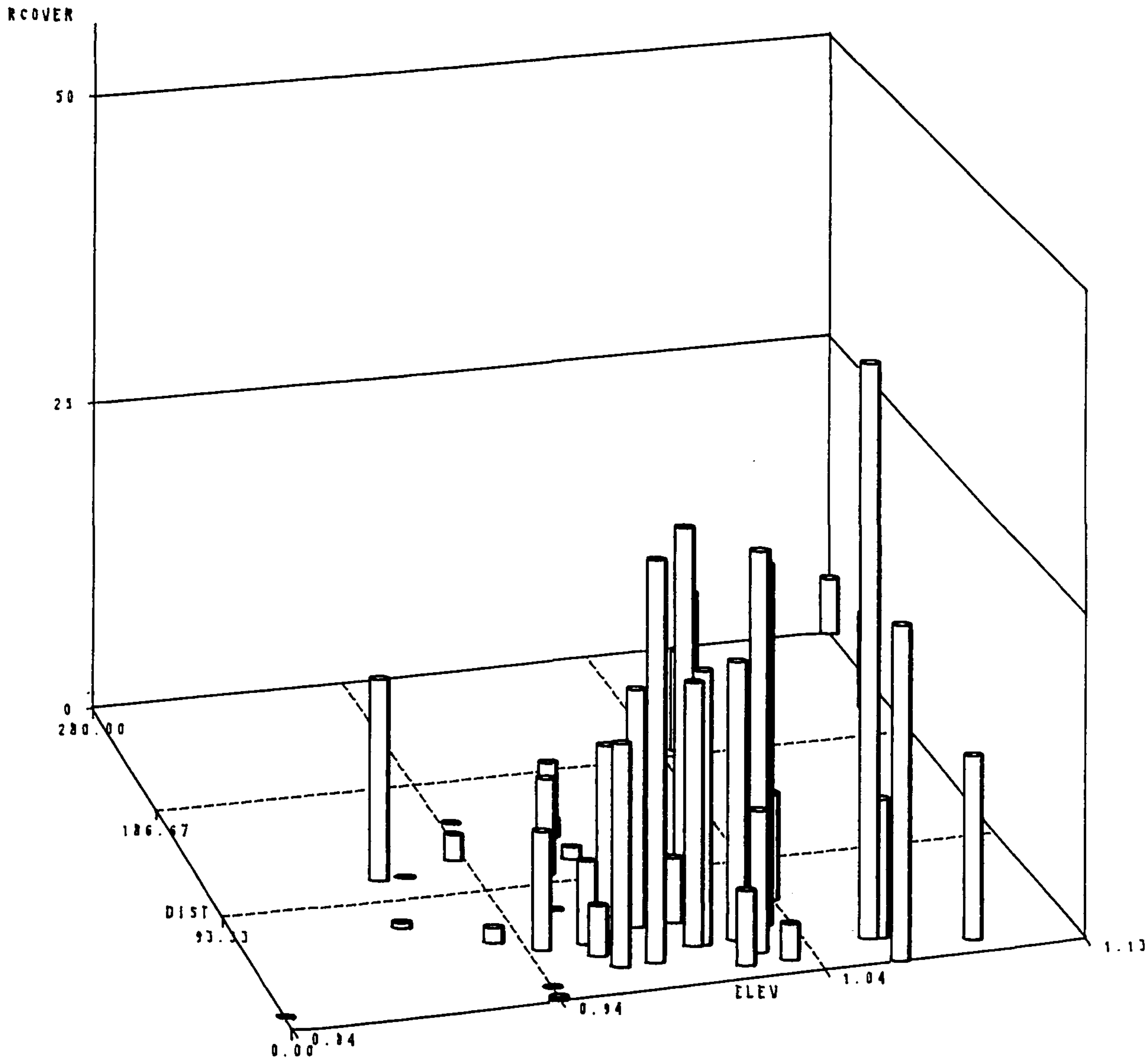
Zizania aquatica



DIST: Distance in meters from the creek.
ELEV: Elevation in meters.

Figure 82a. Relative cover of SpaCyn along the elevation and distance gradient of Sweet Hall Marsh. View along the elevation gradient is emphasized.

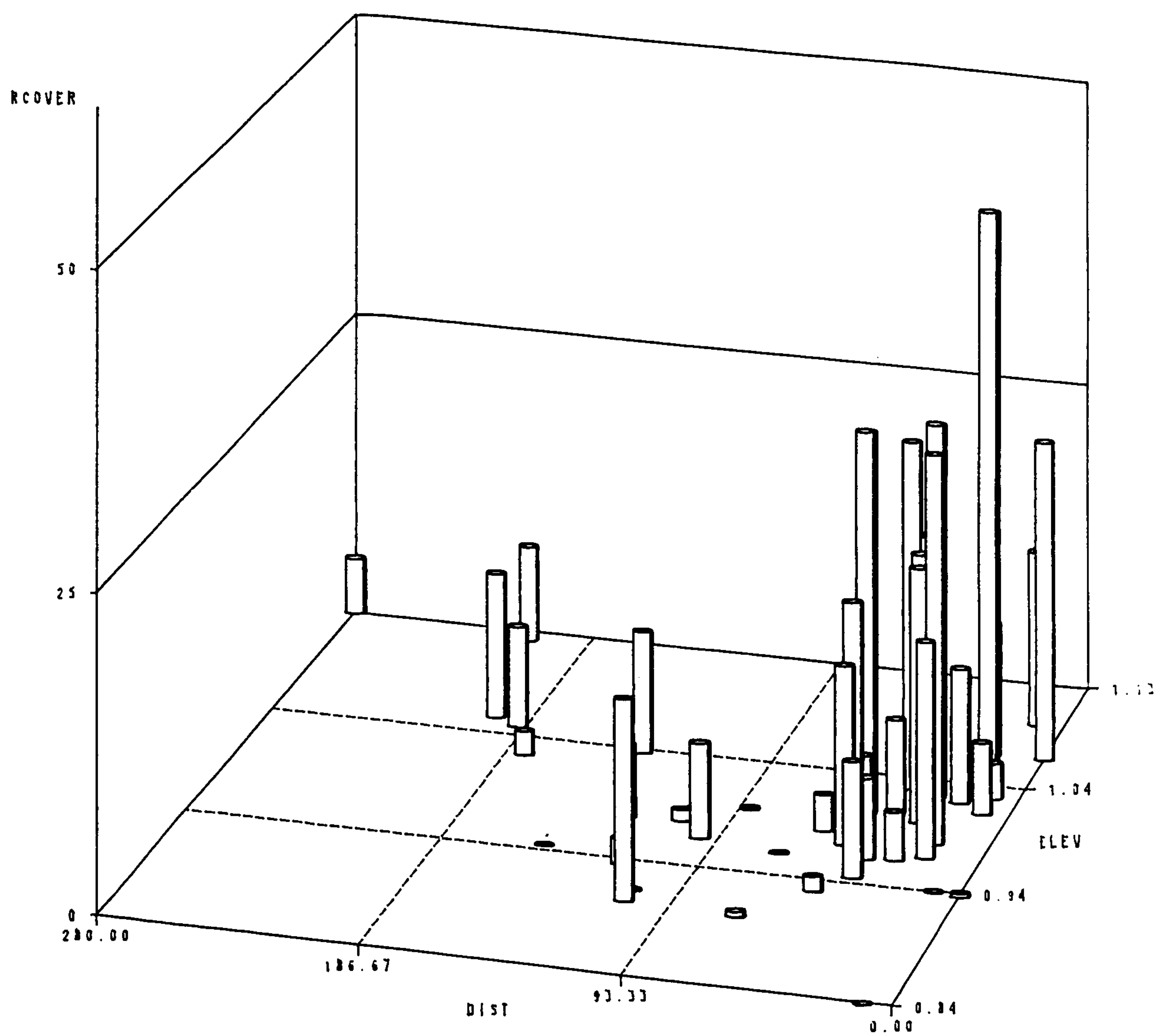
Spartina cynosuroides



DIST: Distance in meters from the creek.
ELEV: Elevation in meters.

Figure 82b. Relative cover of SpaCyn along the elevation and distance gradient of Sweet Hall Marsh. View along the distance gradient is emphasized.

Spartina cynosuroides



DIST: Distance in meters from the creek.
ELEV: Elevation in meters.

percentage of time a species spends inundated over a specific period of time). Sixteen (16) tidal constituents were extracted from the tidal data collected at the site (Table 14). Three (3) of these were long term constituents and were taken from the existing Gloucester Point long term tide data. The mean tide range at the site was 0.73 m (2.37 ft). Mean sea level at the site was 1.17 cm (0.032 ft) higher than at the reference site (Gloucester Point) (see Appendix 3). As expected, the tide at Sweet Hall Marsh was semidiurnal with one tide slightly higher than the other (Figure 83). Steric effects, i.e. the increase or decrease in the elevation of mean sea level due to seasonal effects, were present in the Sweet Hall system. Tides with the greatest height were found in the warmest months and those with the lowest in the colder ones (Figure 84).

Inundation periodicity was calculated seasonally for the mean elevation of individual species (Table 15). An example of a typical inundation curve for Sweet Hall Marsh is shown in Figure 85. The steric effect was obvious as inundation periodicity increased from the winter through the fall. The increase from the winter to spring was the largest, approximately 20% for each species (Table 15). Z. aquatica and B. laevis experienced the most inundation and S. cynosuroides the least (Table 15).

Distance as a parameter: The relative cover data for P. virginia

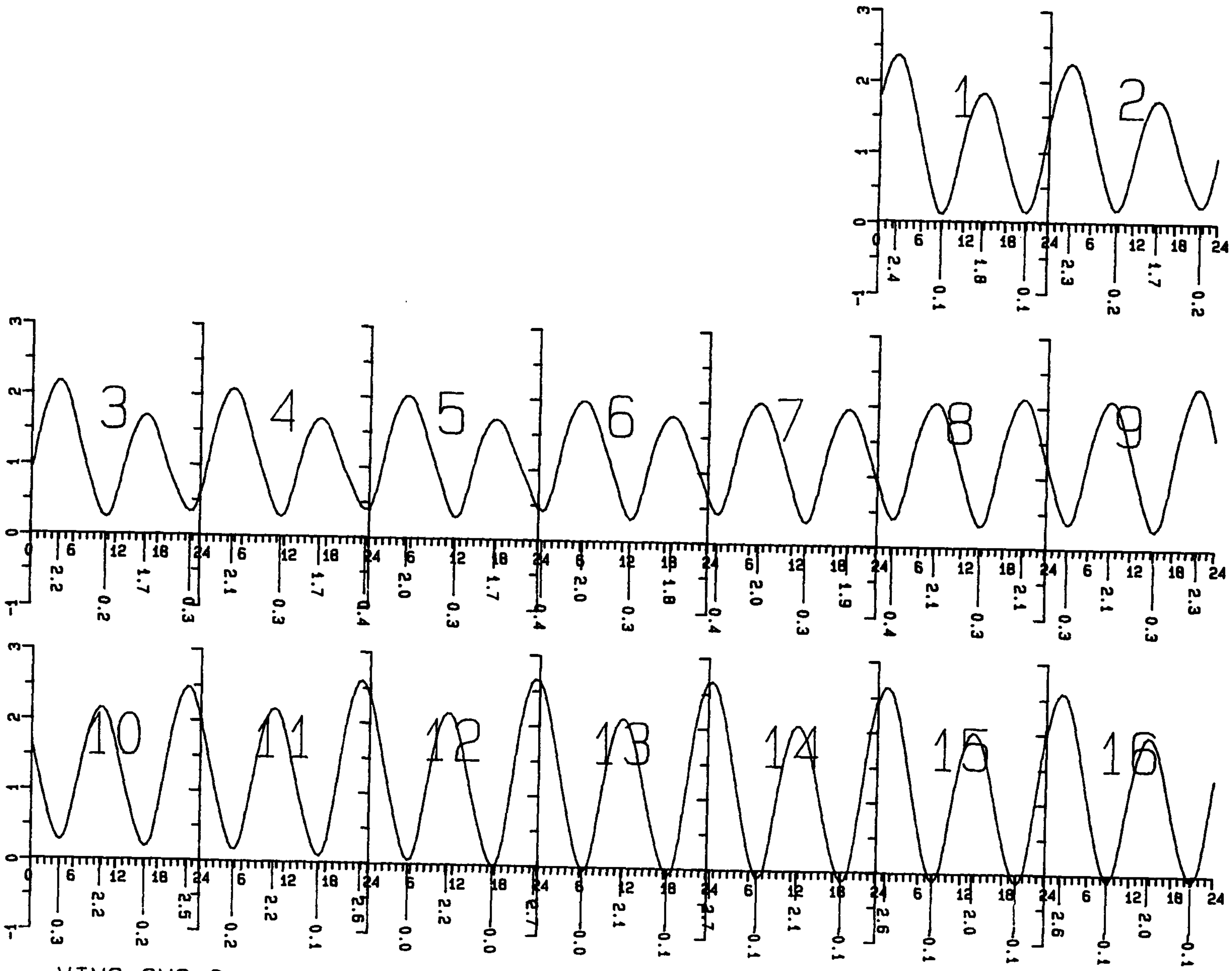
Table 14. Tidal components for Sweet Hall Marsh (see Boon and Kiley (1978) for a complete description). Mean sea level=0.00.

NAME OF PARTIAL TIDES	SYMBOL	SPEED	AMPLITUDE	PHASE ANGLE
Principal lunar	M2	28.9841	1.029	1.9
Principal solar	S2	30.0000	0.142	22.4
Larger lunar elliptic	N2	28.4397	0.188	343.5
Lunar solar diurnal	K1	15.0410	0.133	184.5
	M4	57.9682	0.068	230.9
Principal lunar diurnal	O1	13.9430	0.104	198.0
	M6	86.9523	0.038	57.8
	S4	60.0000	0.019	256.1
	NU2	28.5125	0.039	352.3
	MU2	27.9682	0.025	341.1
	2N2	27.8953	0.027	339.6
Solar semiannual	SSA	0.0821	0.301	69.7
	SA	0.0411	0.322	165.2
	MSF	1.0159	0.024	78.5
Lunar fortnightly	MF	1.0980	0.066	15.7
Larger lunar elliptic	Q1	13.3986	0.020	204.4
Principal solar diurnal	P1	14.9589	0.044	185.5
Smaller lunar elliptic	L2	29.5284	0.029	13.0
Lunisolar semidiurnal	K2	30.0821	0.039	24.1

Figure 83. Example of the tide calendar created for Sweet Hall Marsh. Note the semidiurnal aspect indicative of the East Coast region.

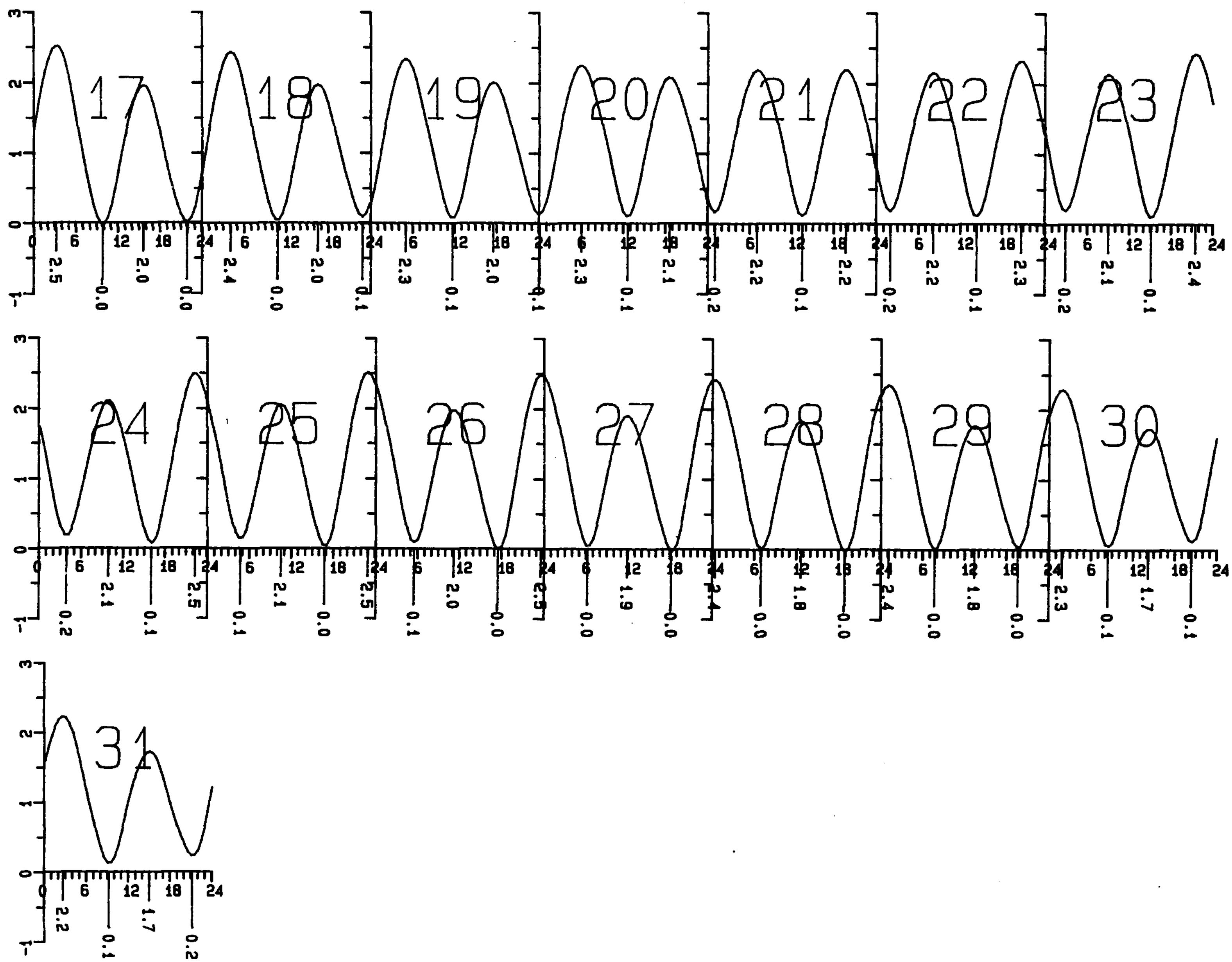
SWEETHALL, Virginia - May. 1987

Time is EASTERN STANDARD. Heights in FEET above MEAN LOW WATER.



VIMS-SMS Computer Center Tide Calendar D.A.E.

SWEETHALL, Virginia - May. 1987 Time is EASTERN STANDARD. Heights in FEET above MEAN LOW WATER.



VIMS-SMS Computer Center Tide Calendar D.A.E.

Figure 84. Annual tide cycle for Sweet Hall Marsh. Note seasonal change in mean sea level (steric effects).

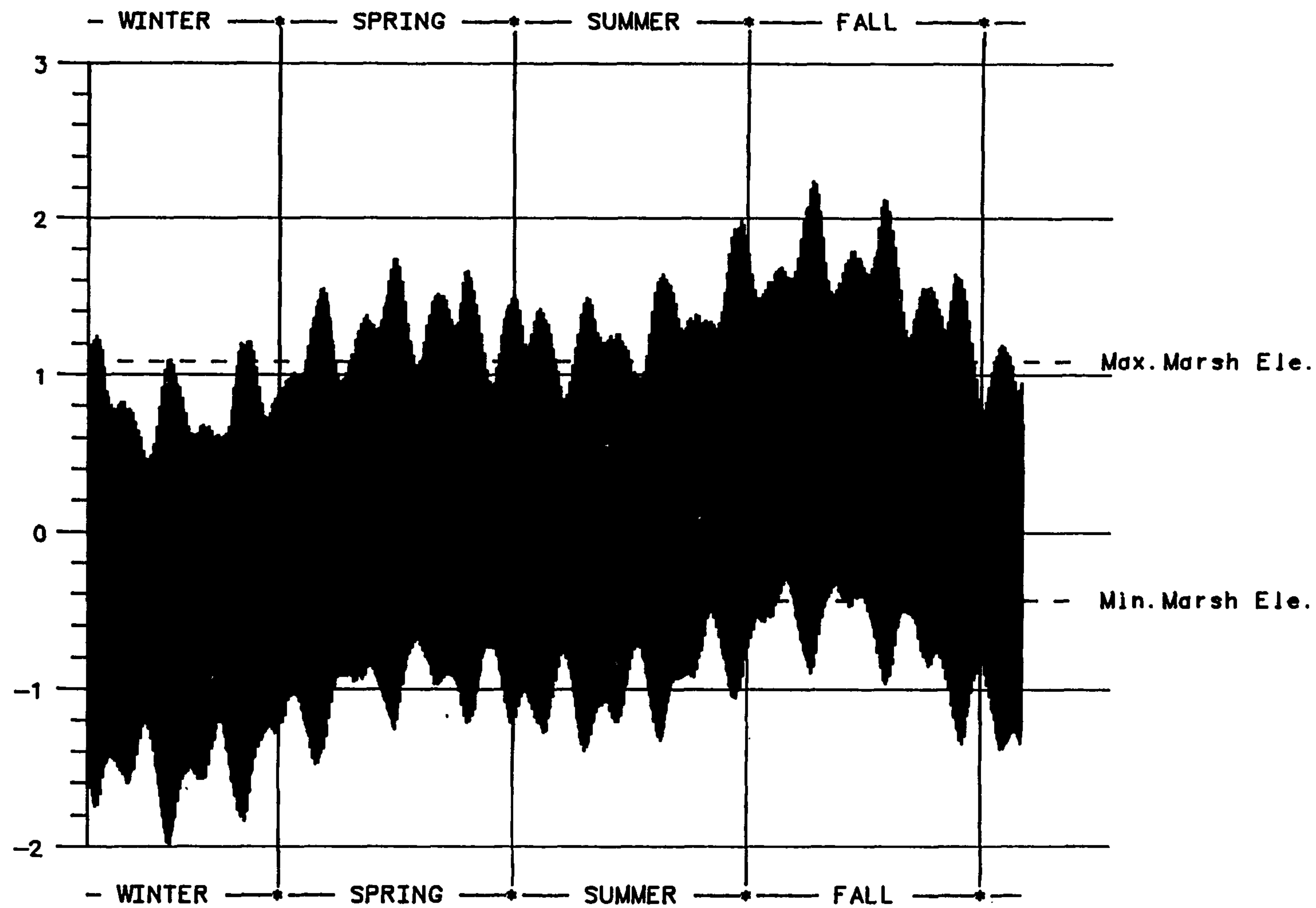
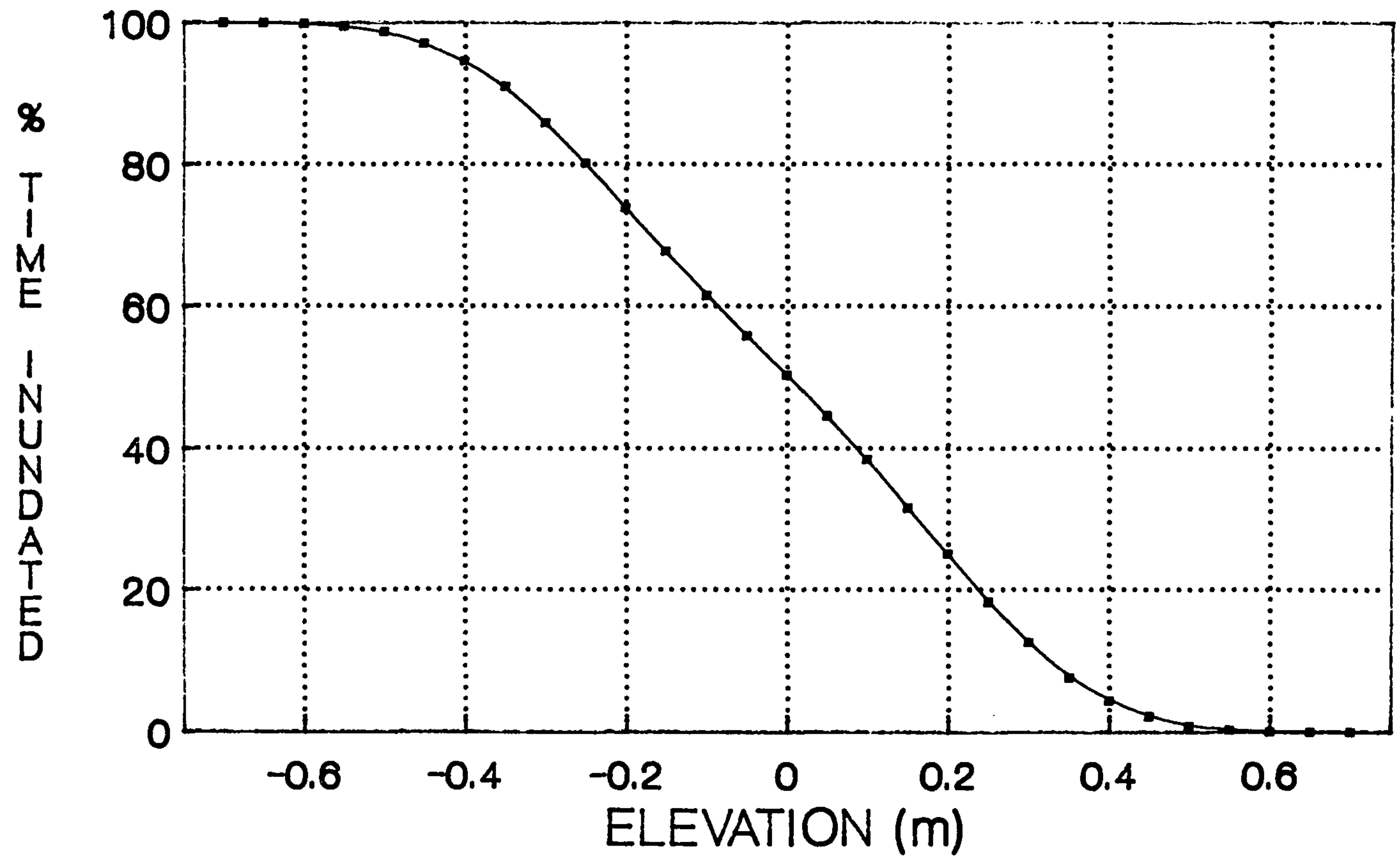

WINTER
SPRING
SUMMER
FALL
3
2
1
0
-1
-2
Max. Marsh Ele.
Min. Marsh Ele.
WINTER
SPRING
SUMMER
FALL

Table 15. Inundation seasonal periodicity. Numbers represent percent of time a specimen at the mean elevation for that species would be inundated. Percentages calculated from species midrange (Table 13).

SPECIES	JAN-MAR	APR-JUN	JUL-SEP	OCT-NOV
Peltandra virginica	10.2	30.4	33.2	38.9
Leersia oryzoides	9.4	29.2	32.3	37.9
Zizania aquatica	10.5	30.8	33.6	39.5
Spartina cynosuroides	8.7	28.3	31.4	36.8
Carex hyalinolepis	6.9	25.1	28.1	34.1
Polygonum punctatum	9.6	29.8	32.9	38.4
Bidens laevis	10.5	30.8	33.6	39.5
Carex stricta	10.2	30.4	33.2	38.9
Echinochloa walteri	10.2	30.4	33.2	38.9
Amaranthus cannabinus	9.4	29.1	32.3	37.9

Figure 85. Inundation curve for Sweet Hall Marsh.

INUNDATION CURVE
1978 TO 1987



0 elevation is Mean Tide Mark

and _S_. _cynosuroides_ were significantly correlated with distance from the thorofare of the plots (P=0.05). Both had negative coefficients (-0.1376 and -0.3844, respectively).

DISCUSSION

I. VEGETATION PATTERN OF SWEET HALL MARSH

Flora

The large number (60) of vascular plant species (macrophytes) occurring in the clip- and cover-plots of this study was appropriate for a tidal freshwater marsh. Doumlele (1976) reported 43 macrophytes occurring in his plots during a similar study of Sweet Hall Marsh. He further noted an additional 37 macrophytes that occurred in the marsh but not in his sample plots. Phillip and Brown (1965) reported 52 macrophytes along the "transition zone" of the South River, Maryland. Odum et al. (1984) listed 168 macrophytes, representing 53 different plant families, that are commonly found in tidal freshwater marshes along the eastern coast of the United States. Odum et al. (1984) suggest the broad expanses of the areas available for plant establishment and the lack of salinity stress contributes to the high number of macrophytes in tidal freshwater marshes.

As would be expected, all of the macrophytes found have a wetland indicator status of facultative, facultative wet, or wetland obligate based on the National Wetland Plant List of Virginia (Reed, 1988).

Vegetation Parameters

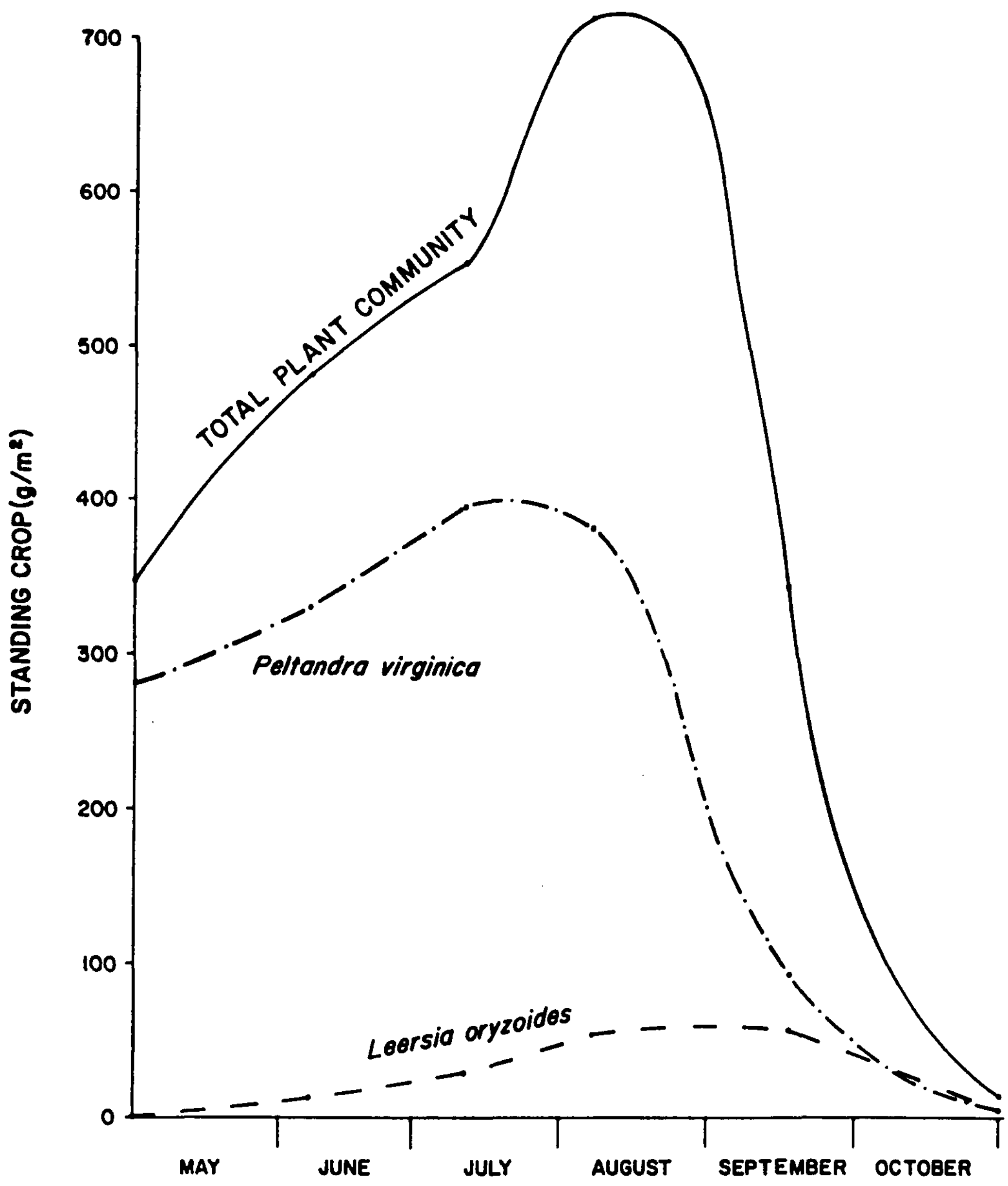
As seen in previous studies, *Peltandra virginica*, a broadleaved non-persistent herbaceous plant, dominated much of the vegetation pattern of the site (Doumlele, 1976; Wohlgemuth, 1988, Booth, 1989). Widespread distribution of P. virginica throughout the marsh (as well as throughout the tidal freshwater reaches of the Pamunkey River) can be explained, at least in part, as a function of seed viability and distribution, the presence of large tuberous rhizomes, and a uniquely well adapted growth pattern.

The seed of Peltandra virginica is surrounded by a gelatinous fluid and enclosed in a tough leathery skin. Little is known of the nature of the fluid or skin, however, one or both provide buoyancy to the seeds. Thus the seeds can float on the waters of the tides, using them as a method of dispersal. It is also possible the fluid and skin may have other functions as well, such as protection from desiccation while in water with a salt concentration greater than that of the seed, protection from winter freeze, and/or protection from ingestion (by rendering the entire structure nonpalatable - personal experience). The latter would quickly dissuade any creature from removing the seed from the wetland/estuary system.

Standing stock of Peltandra virginica was reported from Sweet Hall Marsh as peaking in July (Doumlele, 1976; Wohlgemuth, 1988, Booth, 1989). Doumlele (1976) and this study found the same to be true with areal cover. Booth (1989) found that the growth phase of the macrophytes exhibited an early emergence in March, followed by a lag phase, and then by a rapid growth phase in early summer. This lag phase has been observed in many tidal freshwater macrophytes that have extensive underground rhizomes (Whigham et al., 1976; Walker, 1981). Booth noted this as a possible adaptive advantage for P. virginica in the tidally controlled environment of Sweet Hall Marsh as it would allow for the breakdown of storage compounds in the rhizomes and their subsequent "reallocation" into the shoot tissues. This provides the plant with an adequate supply of nutrients for subsequent phases of rapid growth (Booth, 1989). Further enhancing P. virginica's survivability and early dominance in the marsh is the development of broad leaves which gather large amounts of the light energy. The energy is needed to drive the very active photosynthetic processes which in turn provide the large amounts of complex carbon molecules that comprise the macrophytes large biomass.

The broad leaves, as well as the clustering (caespitose) habit of the macrophytes, blocks sunlight from the area surrounding the plant. This produces an interspecies competitive edge for Peltandra virginica by inhibiting or limiting the light available to other macrophytes. Therefore, late emerging macrophytes must find other available habitat or wait for a decline in P. virginica in order to become established. In fact, a decline in the biomass and areal cover of P. virginica has been reported to occur rather abruptly in August in Sweet Hall Marsh (Figure 86) (Doumlele, 1976; Wohlgemuth, 1989; this study) and has been noted in

Figure 86. Seasonal fluctuation of biomass of PelVir (from Doumlele, 1976).



STANDING CROP (g/m²)
700
600
500
400
300
200
100
0
TOTAL PLANT COMMUNITY
Peltandra virginica
Leersia oryzoides
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER

other tidal freshwater marshes as well (Odum et al., 1984).

In Sweet Hall Marsh, the decline coincides fairly well with seasonal increases in salinity (see Figure 73) as well as with the rise in dominance of other macrophytes (indicated by the large number of macrophytes negatively correlated with Peltandra virginica, see Table 7). A salinity tolerance of less than 0.5 ppt has been estimated for P. virginica (Anderson et al., 1968), a range that is often exceeded in the mid to late summer season in Sweet Hall Marsh. However, no salinity tolerance studies, either in situ or in vitro, have ever been conducted on P. virginica. Therefore, any relationship implied herein remains strictly hypothetical.

Much work needs to be done on the life history, anatomical and chemical composition of Peltandra virginica, an important wetland component in many of our tidal and nontidal wetlands, in order to better comprehend its significance.

Spartina cynosuroides was one of the few macrophytes that did not show a negative correlation to Peltandra virginica. A perennial macrophyte, it also reaches its peak growth in September (Doumlele, 1976; Booth, 1989; Wohlgemuth, 1989; this study). Its apparent independence from P. virginica may be due to its preference for the more restrictive levee habitat. S. cynosuroides had the highest and narrowest elevation range of the macrophytes investigated in this study. Ontogeny of the levee habitat is through rapid settling of sediments from the oncoming tides. The persistent habit of S. cynosuroides (i.e. culms remain standing throughout the winter) and thick interwoven roots and rhizomes act as a sediment trap and stabilizer. The incoming sediments would be rich in nutrients and salts. The latter may provide a competitive edge to the more salt tolerant S. cynosuroides. Therefore, there may be a dependent relationship between the formation of a levee and survival of S. cynosuroides populations in Sweet Hall Marsh. P. virginica, on the other hand, does not have persistent culms nor tightly interwoven rhizomes (individual macrophytes may asexually reproduce and provide tightly interwoven colonies, however these are small in area) and are poor sediment traps or stabilizers during the non-growing season. Thus, any sediment gained by the summer growth of P. virginica may be lost via erosion or surface runoff once the vegetation dies back. This is particularly true of the creek bank zone of Sweet Hall Marsh that receives most of the winter storm wave energy (Ledwin, 1988). Were P. virginica dominant further back into the levee zone, the levee would probably not survive.

The other two macrophytes that showed no relationship to Peltandra virginica (Bidens laevis and Polygonum punctatum) were both macrophytes that occur as annuals in their northern range and perennials in their southern range (Gleason, 1952; Radford et al., 1968). In Sweet Hall Marsh both were observed as predominantly annuals. Therefore, only during extremely mild winters would individual macrophytes be able to survive into the next growing season. Both also have narrow leaves in respect to P. virginica, a morphological condition that would make them poor competitors for light during the P. virginica peak. This study found that the midrange elevation of B. laevis was one that had a higher inundation period than the midrange of P. virginica (Table 13). This indicates that B. laevis can withstand a greater percent of time inundated than can P. virginica, therefore taking advantage of the available lower elevations. The exception to that would be on the creek bank zone where P. virginica dominated even in the lower elevations. The current and wave energy produced by the tides of the area could possibly be too high for establishment of the seeds of annual macrophytes. P. virginica could become established in the creek zone through several methods (see above).

P. punctatum did not have the same affinity for lower elevations. Its lack of relationship to Peltandra virginica may be due to physiology, such as high photo-reactivity in low light.

Unlike Peltandra virginica, Leersia oryzoides has no special seed coat nor is it an early emergent. In fact, although young seedlings were numerous in May, L. oryzoides growth may have been suppressed by the shading effect of the ubiquitous P. virginica. L. oryzoides is, however, a perennial and emerges from a slender creeping rhizome. The rhizome, as mentioned above, will provide a preliminary source of nutrients for early survival and, in this case, may supplement the nutrient needs of L. oryzoides until the shading or other negative competitive effects of P. virginica are decreased by its decline. The added energy would position the macrophyte, as it would any perennial, to take advantage of the habitat that becomes available. Needles to say, if this mechanism were to work, the open habitat must occur in the immediate area of the rhizomes. If no rhizomes are present, other mechanism must be involved in revegetation. L. oryzoides can take advantage of at least two other mechanisms; dispersal of viable seed and dispersal of viable fragments of the rhizome (Kadlec and Wentz, 1974). Seed production of L. oryzoides has been reported to be 154 kg/hectare, a moderate production rate in comparison to other wetland macrophytes (Kadlec and Wentz, 1974). No information was available on the production of rhizome fragments. However, for fragmentation to occur, a disturbance must occur. In Sweet Hall Marsh disturbance may occur through muskrat activities, ice rafting, water fowl feeding, and/or wave/wake erosion (personal observation). Both mechanisms of distribution rely upon tides for dispersion.

Interpretation of Aerial Photography

The largest problem encountered with interpretation of the aerial photographs was the change in total area of the wetland from photograph to photograph (Table 11). Although calculation of relative composition of vegetation associations alleviated some of the problem, it is still important to understand why the variation occurred.

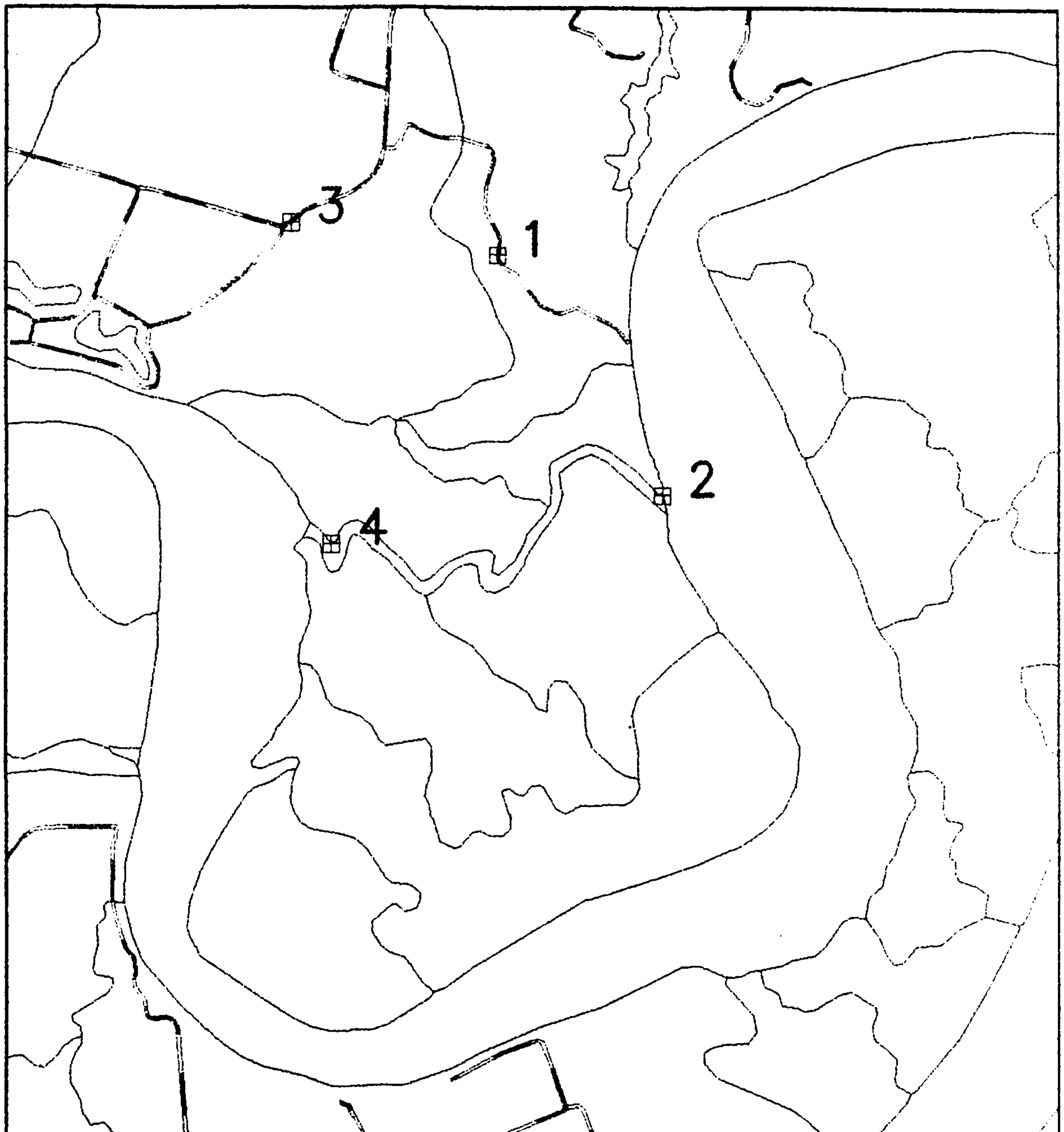
Three steps were necessary for interpretation of the aerial photographs used in this study:

1) producing the cartography - transferring (mapping) the needed information (the vegetation associations) from each photograph onto a digitizing medium (prepared acetate),
2) digitizing the vegetation data - transposing the acetate maps into binary data for use in the GIS computer system, and
3) mapping the vegetation data - generating the area of each vegetation association that was determined from each aerial photograph.

It is very unlikely that any error was introduced through the GIS mapping processes. The GIS system uses fixed geographic points (road crossings, road-railroad crossings, buildings, etc.) common to all of the aerial photographs to fix geographic extremes of a system that is being mapped. The scale of each photograph, relative to the fixed points, is then calculated as a linear function of the distance between each point. For this study, four geographic points were used; two road-railroad crossings and two marsh points (Figure 87).

Any error that would occur through the digitizing of the vegetation associations as outlined in the cartography of the photographs was minimized by using only an experienced technician. The same technician was used for digitizing all cartographic maps.

Figure 87. Geographic information system reference points.



DIGITAL REGISTRATION POINTS

TIC COORDINATES TAKEN FROM

UTM ZONE 18 GIVEN IN METERS

ROADS

SHORELINE

	X	Y
1 –	333008.68	4160087.00
2 –	333685.00	4159115.00
3 –	332156.09	4160219.00
4 –	332324.09	4158197.00

In order to assure an unbiased delineation of vegetation associations when producing the cartography of each photograph no base outline was used (i.e. the outline of the marsh was re-drawn from photograph to photograph). As well, no previous cartograph was used as a reference to draw "difficult" delineation lines of a succeeding photograph. Therefore, the boundaries shown on a cartograph are representative of a single photograph.

Therefore, cartography is suspect. The loss or gain of shrubs and/or vines along a line of delineation appears to be common. Although the hydrology and soil conditions would not have changed (thus, the line of delineation between the uplands and wetlands would, by definition, not have changed), visual changes in the photographs from a herbaceous wetland to shrub wetland were probably misread.

II. VEGETATION CHANGES

Comparison with Previous Study

The changes that occurred in Sweet Hall Marsh between 1974 and 1987 can be interpreted as: 1) changes that are part of a yearly variation in population dynamics of the macrophytes; 2) changes in response to long term variation in environmental parameters of the ecosystem; or 3) a combination of both. It is not known if yearly variation within a system could produce statistically significant differences in vegetation patterns of a wetland system as was found in this study. Unfortunately, the results from this study do not directly address the issue as the data show change over a single 13 year time period.

However, several results from this study stand out. First, there was a noticeable difference in the distribution patterns of perennials vs. annuals. The annuals were more variable in their distribution dynamics than the perennials. Seed dispersal would be via wind, tides, or animals. Since annuals are reliant upon open habitat at the time of germination, they can be considered the "opportunistic" strategist of the marsh. Therefore, yearly variation in distribution may be normal and the value of annuals as indicators of trends would be suspect. Perennials, on the other hand, would tend to stay in place. A temporal change in the distribution of perennials could be seen as indicative of changes in the surrounding environment. The amount of time a species takes to react to changes would, of course, depend upon the degree of change and the plasticity (adaptability) of the species. Future work should be oriented toward investigating the response of perennial species to small changes in environmental parameters, particularly changes in salinity and inundation periodicity.

Secondly, the increased importance value of Spartina cynosuroides indicates a shift in dominance within the vegetation pattern. Productivity numbers for the highest five species for each study also exhibit a shift. Peltandra virginica dominated productivity in 1976 (70.3% of the total productivity of the five species), but made up less than 45 percent during this study (Table 16). If dominance is defined as the species whose sum(s) totals greater than 50% (Muller-Dombois and Ellenberg, 1974), the vegetation pattern during this study would be codominated by P. virginica and S. cynosuroides, but only by P. virginica in 1976.

III. ENVIRONMENTAL PARAMETERS

Salinity: Seasonal Trends

Salinity increases in an estuary can be caused by decreasing the dilution effect of freshwater input by decreasing the amount of fresh water that reaches the estuary. This is usually caused by natural (e.g. drought) and/or man-made processes (e.g. stream diversions to another watershed or dam construction of riverine tributaries (usually for water supply reservoirs)).

As fresh water enters an estuarine system as surface flow or freshets, the salt gradient of the estuary becomes diluted (Knauss, 1978; Bradshaw and Kuo, 1987). However, as indicated in this study, this relationship is not always easy to see. Even though rainfall in the watershed that includes Sweet Hall Marsh is highest in the summer (Brooks, 1983), salinity reaches its peak during the same time period (see Figure 73).

An explanation for this apparent paradox may be realized by adding evapotranspiration processes into the water budget. Rykiel (1984) found that an average of 176 mm/month (69.3 inches/month) was lost to evapotranspiration in the Okefenokee Swamp in Georgia. The largest water loss was in July and the smallest (21 mm/month) in December (Rykiel, 1984). Hammer and Kadlec (1983) found that radiation played a dominant role in evapotranspiration and that as radiation increased, evapotranspiration increased. Since solar insolation in the Chesapeake Bay increases to a peak in the late summer (Figure 88) (Wetzel and Neckles, 1986), evapotranspiration would also peak in the late summer. Therefore, due to the seasonal increase in evapotranspiration the freshwater entering the watershed in the late summer would decrease in spite of increases in precipitation.

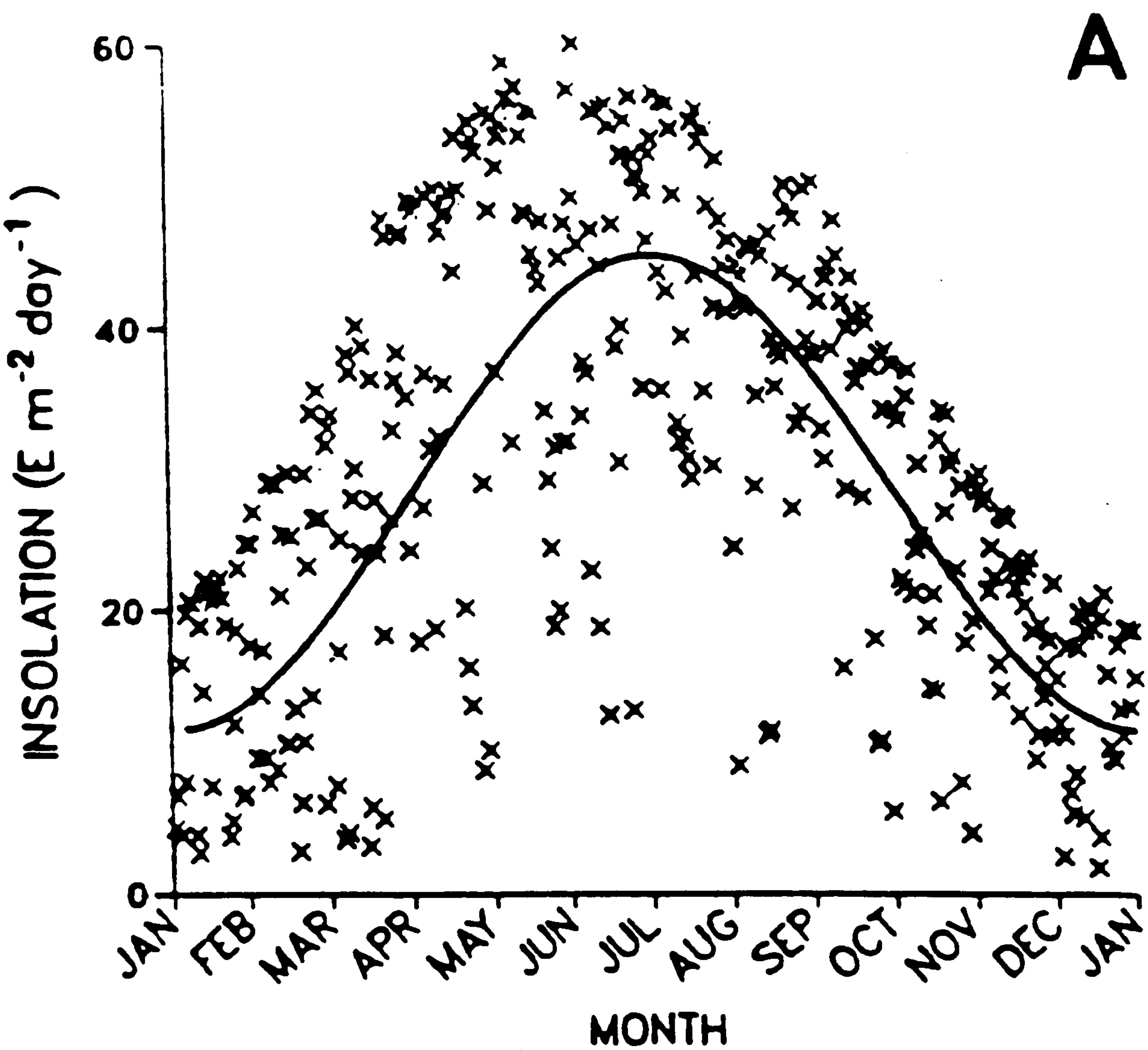
Salinity: Yearly Trends

The distance upstream that salinity stresses wetland vegetation is a function of the basin volume and freshwater runoff into an estuary. If a basin were to increase in size and/or runoff to decline, the tidal volume would increase and, therefore, more salt water would enter the estuary. The net effect would be an increase in the reach of salinity stress farther upstream (Knauss, 1976). If the basin were to decrease in size and/or the run off volume increase, the effects of salt would not be felt as far upstream. That is, the reach of salinity stress would

Table 16. Net productivity of Sweet Hall Marsh. 1976 data after Doumlele, 1976. (weights in grams/square meter/year).

1976			1987		
SPECIES	WEIGHT	%	SPECIES	WEIGHT	%
PelVir	369.72	70.3	PelVir	214.13	42.6
LeeOry	57.95	11.1	SpaCyn	145.42	29.6
PolPun	45.29	8.6	LeeOry	57.92	11.8
PonCor	30.84	5.9	ZizAqu	55.23	11.2
AneKei	22.23	4.2	CarHya	18.65	3.8
TOTAL	526.03			491.35	

Figure 88. Seasonal fluctuation in solar insolation in Chesapeake Bay (from Wetzel and Neckles, 1986).


A
INSOLATION (E m-2 day-1)
60
40
20
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
MONTH

decrease.

Changes in the basin size at Sweet Hall Marsh may be brought about by eustatic sea level rise, isotectonic effects, and/or local events (ground water withdrawal). Together, these three parameters control the relative sea level of the site. Any change in these three parameters, leading to an increase in the elevation of relative sea level, would increase the volume of water entering the basin and, therefore, increase the upstream reach of salinity. Research in the Chesapeake Bay indicates that relative sea level is rising (Hicks, 1972; Froomer, 1980b) (Figure 89). Thus, one would hypothesize that the salinity in the Sweet Hall Marsh area is on the rise.

Unfortunately, the data compiled by this study was inconclusive. Although a best fit regression curve indicated a trend toward an increase in mean annual salinity, the results were not statistically significant ($P>0.05$).

The lack of significance may be attributed to limitations inherent to the data set used in the analysis. The data set was not complete: within each year of the slack water monitoring program, not all months were sampled (Brooks, 1983) (Table 17). A long term salinity average would therefore be biased toward the years in which that month was sampled and would not accurately represent a long-term average (Bradshaw and Kuo, 1987). Furthermore, the sampling period did not take

Table 17. Months of Slack Water Surveys (High and Low) for 1970-1980

Pamunkey River

	1970		1971		1972		1973		1974		1975		1976		1977		1978		1979		1980	
	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L
January									X													
February										X												
March			(X)	(X)	(X)		X															
April			(X)		X	X						(X)	(X)							△X		
May			X		(X)	X		X	(X)		△X		(X)	(X)		△X						
June				X						X			(X)			△X		△X		△X	X	
July								(X)	(X)	(X)					△X	△X	△X	△X	X	X		△X
August		X	(X)				X	X		(X)						△X				X		△X
September			X		(X)	X				(X)				△X	△X	△X		△X	X	△X	△X	
October				(X)	(X)	(X)		(X)	(X)		△X				△X			△X				△X
November	X	X	(X)		(X)				(X)		X									X		
December			X							X				△X								

X : Temperature, Salinity, D.O.

(X): T, S, D.O., B.O.D.

△X: T, S, D.O., B.O.D., Chlorophyll and Nutrients tide affects into consideration. Since no attempt was made to time the surveys with spring and neap tides, the effect of major tidal components on salinity variation is missing from the data set.

Vegetation Response to Salinity Stress

Plant cells cope with increasing salinity stress (i.e. increases in the salt concentration of the water column and/or soil) via osmosis. Osmosis is the active transport of water by a plant through a permeable cell wall (membrane) from the solute with the lowest concentration of salts to one with the highest concentration in an attempt to neutralize the higher concentration solute. The movement of water continues until the solution concentrations are equal on each side of the wall. Therefore, in the event of an increase in exposure to salt water, there would be a net loss of interstitial water from the plant to the outside environment.

In macrophytes that have large amounts of parenchyma cells (e.g. Peltandra virginica), salinity stress, due to the thin walled nature of the cells, may be more pronounced. These plants would quickly desiccate and lose turgor under increased saline conditions due to the rapid loss of water across the thin walls. On the other hand, water loss would be minimized by plants that have a large number of cells with thickened cell walls. The thicker walls decrease direct contact between the living plant tissue and high concentration solute.

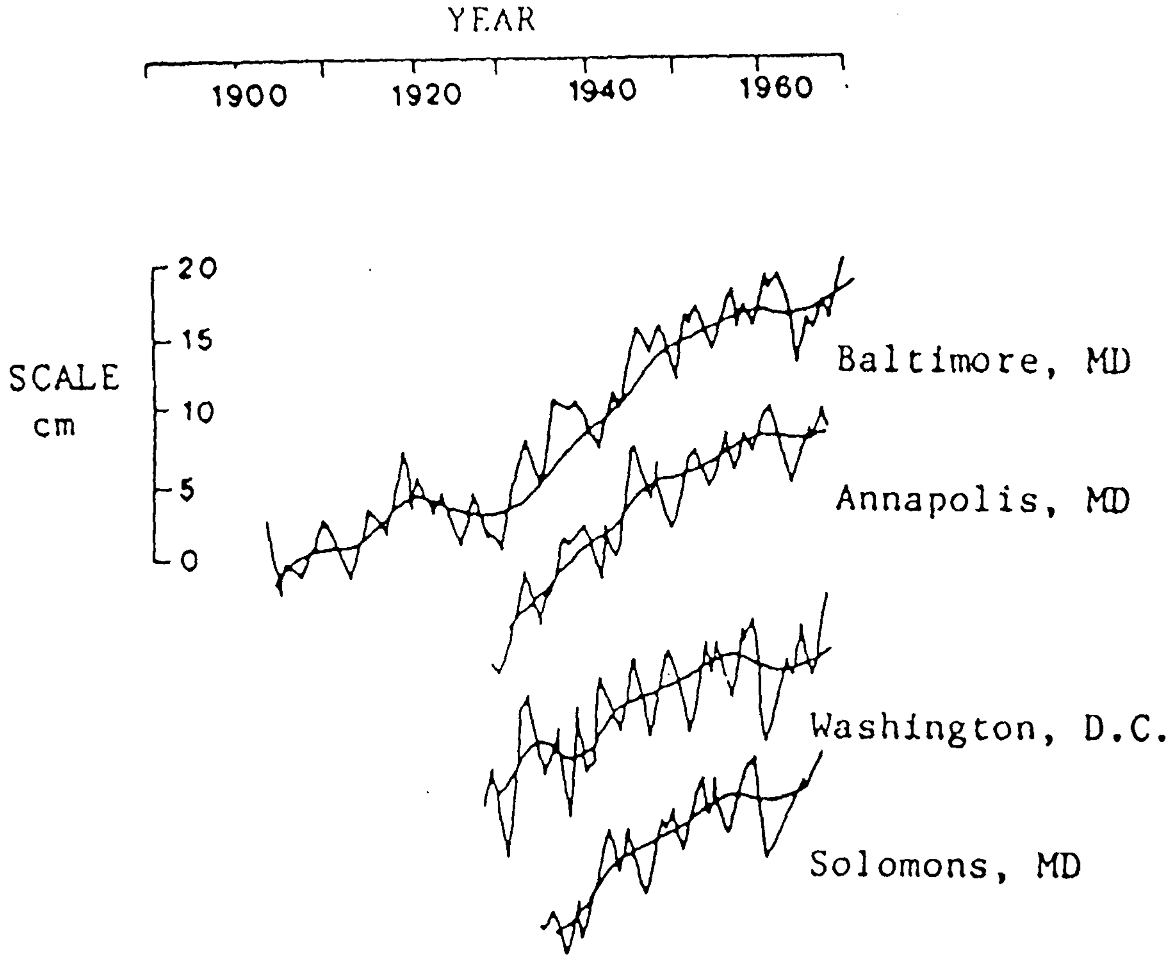
The above could explain, in part, the early dominance of Sweet Hall Marsh during the early growing season (time of low salinities) by Peltandra virginia, a thin cell walled macrophyte. As well, it could explain the seasonal shift during the mid to late growing season (times of higher salinities) to Leersia oryzoides, Zizania aquatica, and Spartina cynosuroides. The latter all contain large numbers of collenchyma and sclerenchyma cells (thick walled cells).

Tides and Inundation Periodicity

As seen in Table 15, steric effects of tides can cause large changes in inundation periodicity from season to season. The effects of these seasonal changes will manifest themselves in two way: 1) changes in inundation periodicity and 2) salt stress. During the mid to late growing season, the time of highest inundation periodicity, there will be an increased stress associated with anaerobic soil conditions of a longer duration and, since salinity of the estuary is highest during the season of peak inundation, there will be an associated increase in salt (osmotic) stress. Therefore, growth conditions in the marsh will be more stressed in the late than in the early growing season. The vegetative response will be toward more flood and salt tolerant macrophytes.

Plant damage due to flooding is normally visible in the roots, stems, and leaves. The extent of the damage varies from species to species. The damage can include die back of roots that were produced

Figure 89. Sea level rise on the Atlantic Coast (from Froomer, 1980b and Hicks, 1972).

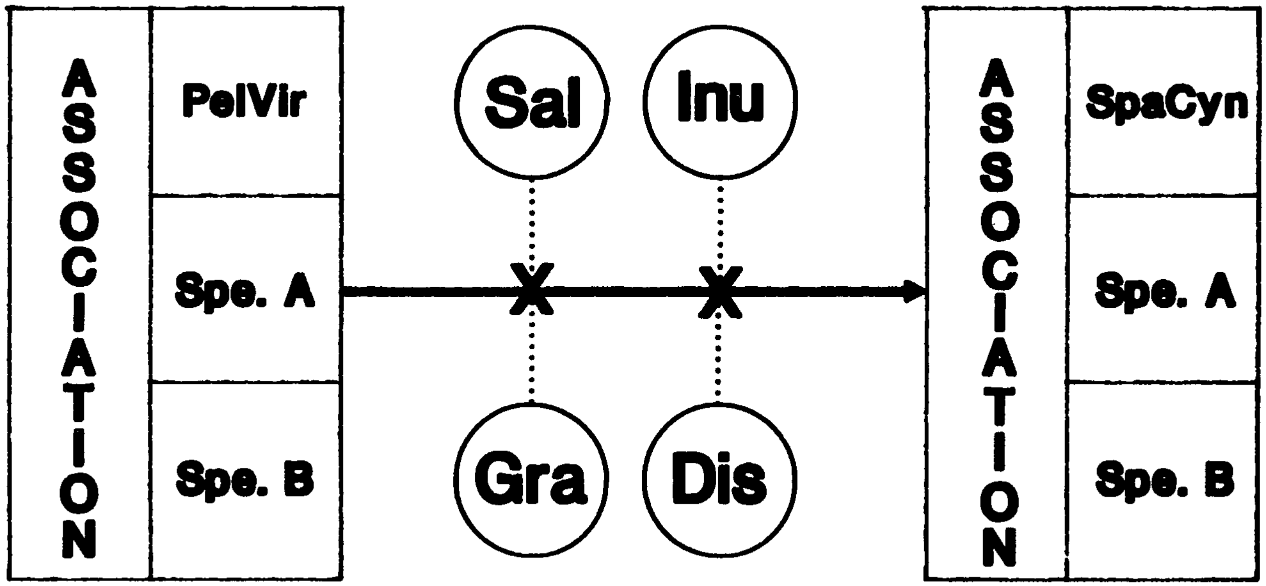

YEAR
1900
1920
1940
1960
SCALE
cm
20
15
10
5
0
Baltimore, MD
Annapolis, MD
Washington, D.C.
Solomons, MD

under aerobic conditions (Broadfoot and Williston, 1973), hormone imbalance (possibly due to root loss), decreases in water and nutrient uptake, photosynthesis, and transpiration (Teskey and Hinkley, 1980).

IV. CONCEPTUAL MODEL

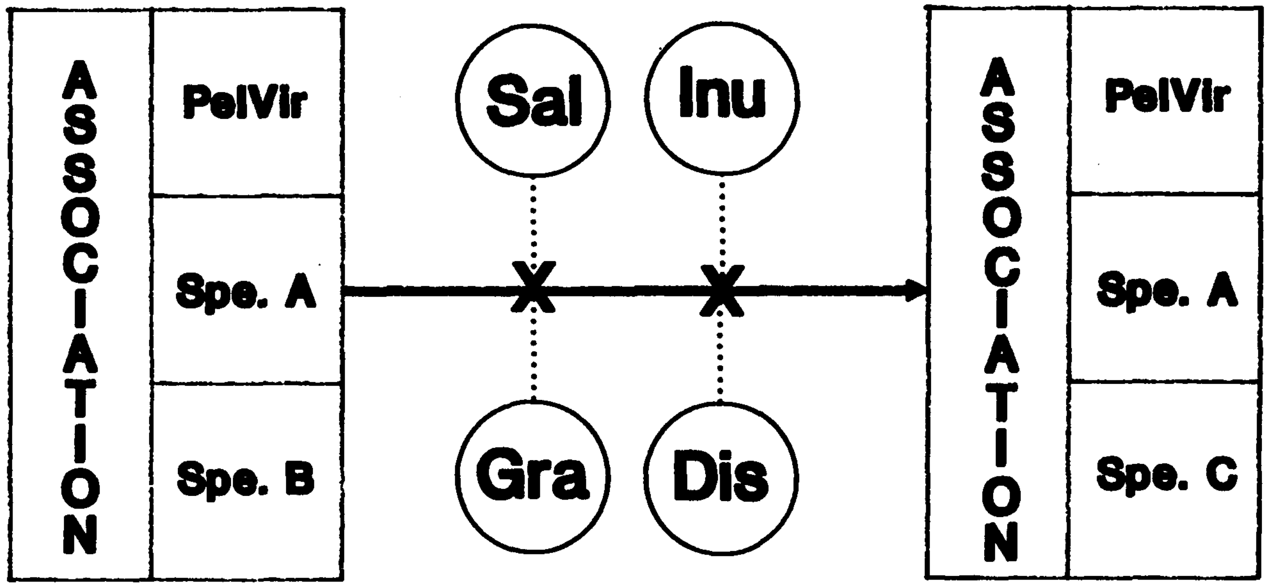
It is evident that any vegetation model of Sweet Hall Marsh must be driven by a number of physical and biological parameters. The most important ones are salinity, inundation periodicity, interspecific competition, and grazing. The model presented is made up of a vegetation pattern which, in turn, consists of a mosaic of vegetation associations within the pattern. A vegetation association consists of a plant community dominated by one or several macrophytes. For example, three major associations can be defined for Sweet Hall Marsh; the *Peltandra virginica* dominated creek bank, *S. cynosuroides* dominated levee-overwash zone, and the mixed marsh area. Even though the mixed marsh area was not dominated by one or two species, the composition and physiognomy of the zone was consistent. A change in the dominant macrophyte(s) of a vegetation association would constitute a change in the association type (Figure 90) while minor species changes would not (Figure 91). A change in an association would represent a change in the vegetation pattern (Figure 92). It is important to note that the model does not reflect a quantitative change in a pattern nor association. However, a change is calculated using quantitative vegetation community data. The model does,

Figure 90. Conceptual vegetation pattern change model. Changes in dominant species within an association constitutes a change of association type.



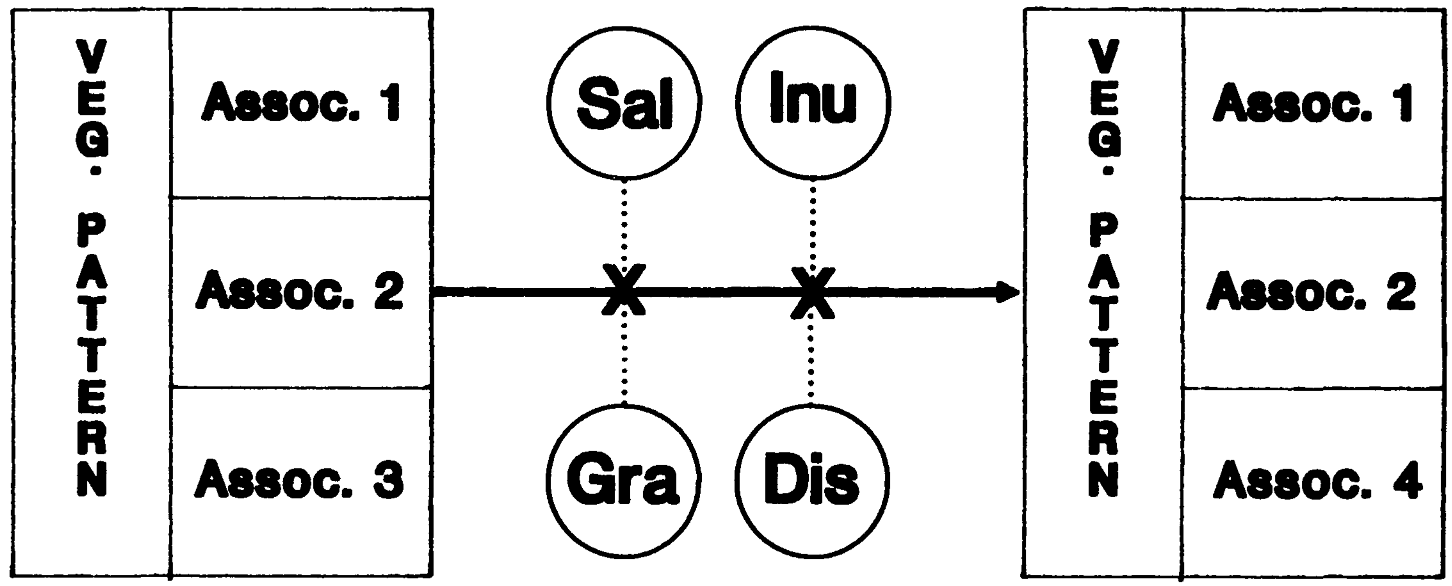
Vegetation Model: Temporal Changes in Vegetation Associations

Figure 91. Conceptual vegetation pattern change model. Minor changes in species <u>not</u> leading to a change in the dominant species of an association does not change the association type.



Vegetation Model: Temporal Changes in Vegetation Associations

Figure 92. Conceptual vegetation pattern change model. A change in an association constitutes a change in a wetland vegetation pattern.



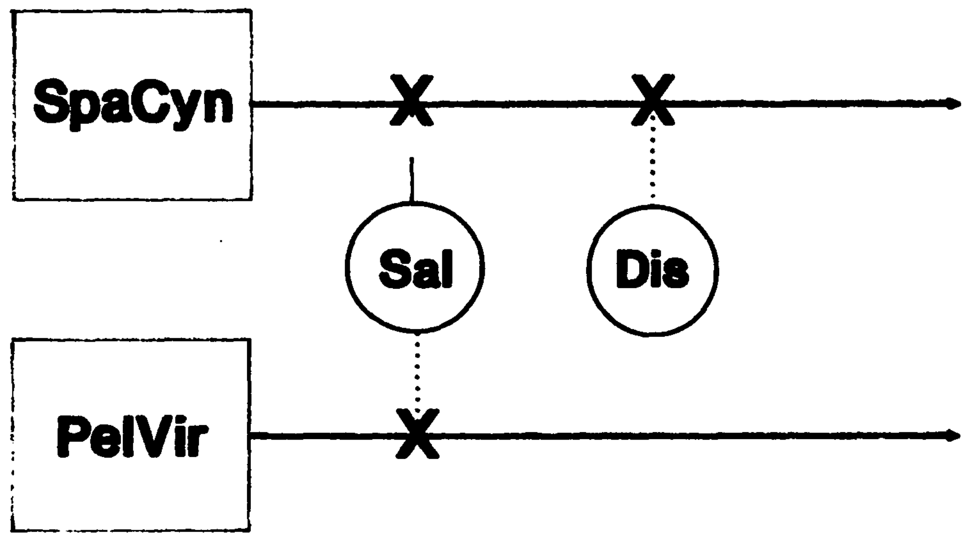
Vegetation Model: Temporal Changes in Vegetation Pattern

however, lay the foundation for such a quantitative assessment. Where the marsh is grided off at workable intervals, say 10m x 10m for example, the association at each grid could be determined (possibly through aerial photography). Quantitative modeling could then proceed on a cell by cell basis. Such interactive models have been developed for coastal Louisiana (Sklar et al., 1985).

The mathematical model developed for this study also provides for individual association changes to take place. However, no spatial changes are currently available in the model, although, there is a mechanism in place to identify each cell.

Salinity affects the conceptual model seasonally and annually. The effects would be on a macrophyte level. Seasonal effects are seen by the vegetation as an increase in stress in the middle to late growing season. The most prominent macrophyte in the marsh, *Peltandra virginica*, apparently reacts negatively to the increased stress and declines in cover and density. Other important macrophytes, such as *S. cynosuroides* react positively to the increase in salinity. Conceptually, this can be modeled as a seasonal cycle of salinity and macrophyte carbon storage (Figure 93). As salinity increases, the carbon stored as *P. virginica* tissue decreases and increases as *S. cynosuroides* tissue. Thus, a negative control gate connects salinity and *P. virginica* and a positive one salinity and *S. cynosuroides* (Figure 93). The data from

Figure 93. Interspecies conceptual model. Salinity is modeled as a gate that effects Spartina cynosuroides positively and Peltandra virginica negatively. To date, no interactive effect between these two species is known.



Carbon Flow Model
No interspecies competition

this study demonstrates that P. virginica and S. cynosuroides do not strongly interact. Therefore, no link between them is needed in the model. However, research into interspecific competition for nutrient availability could change that. The data also showed that S. cynosuroides was positively correlated with elevation and negatively with distance from major creeks.

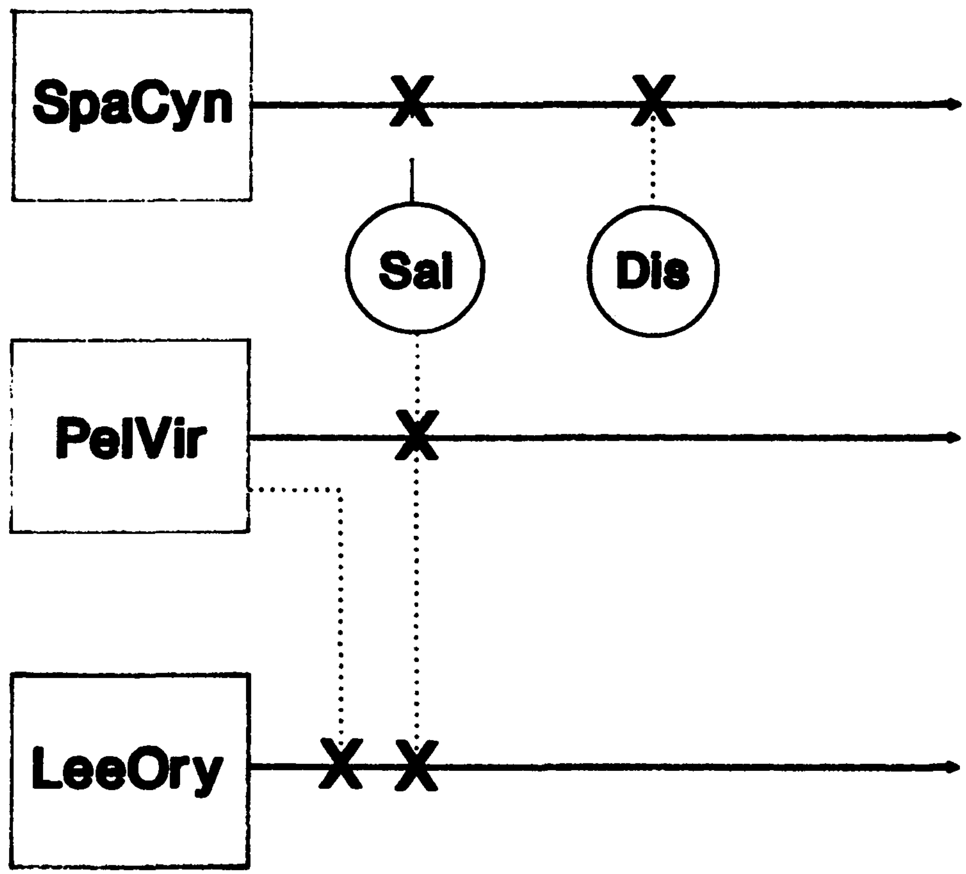
L. oryzoides, on the other hand, demonstrated a positive correlation to Peltandra virginica but no clear link to salinity. Therefore, a negative control gate would run from P. virginica to L. oryzoides (Figure 94).

V. WETLAND MANAGEMENT AND THE ROLE OF VEGETATION PATTERN MONITORING

Much could be learned of a wetland ecosystem by analyzing the spatial and temporal changes that occur in vegetation patterns. Small changes in macrophyte distribution, numbers, and importance in a wetland pattern could be used to indicate changes in environmental parameters of a wetland system. In some cases, we may be able to detect changes in environmental parameters that are beyond the ability of our technology and/or knowledge to measure.

As vegetation patterns change, the value of a wetland to specific species will change. Waterfowl that rely on the grain of Northern wild rice (Zizania aquatica) for subsistance would need to find new sources of the grain if the vegetation becomes more halophytic.

Figure 94. Interspecies conceptual model. The interaction between _Peltandra virginica_ and _Leersia oryzoides_ is modeled as a negative feed back loop from _P. virginica_



**Carbon Flow Model
With interspecies competition**

Other wildlife would be affected as well. Muskrats appear to favor wetlands that have a combination of succulent species for food and fibrous species for den building (personal observations). As the vegetation patterns change to more halophytic species, many of the muskrat's preferred foods would disappear. Early detection of the changes in the vegetation would provide time for managers to plan for the loss of a food source. Corrective management steps, such as field or marsh plantings, could be put into action before, instead of after, the changes occur.

An understanding of the changes in wetlands vegetation patterns could serve as an early detection and warning system for extremely subtle long term climatic adjustments. Data suggest that we are in a period of global warming (Barnett, 1983; Environmental Protection Agency, 1987). A consequence of warming would be a rise in sea level. The change in the climate would be seen in wetland vegetation patterns as species shifts to more adopted populations. As this study shows, it is possible to measure fine scale shifts in vegetation.

With further understanding of the trends seen in vegetation patterns, our ability to predict changes in our physical environment will improve. Furthermore, our ability to manage for these changes will be greatly enhanced.

CONCLUSIONS

1. Changes did occur in the species composition of the vegetation associations and pattern of Sweet Hall Marsh. Short term biological changes were detected when the data from this study was compared to a previous study. From the evidence presented, it is hypothesized that these changes may represent linear trends towards a more oligohaline system in response to salinity increases in the general vicinity of the wetland. However, more research is needed to determine what role can be attributed to yearly changes in species population dynamics in response to yearly changes in the driving forces of the system. As well, more information is needed to determine the role muskrats play in the system.

2. Changes did <u>not</u> occur in the complex diversity measurements of the wetland. It is possible that complex diversity indexes are misleading when used to identify vegetation changes in a system over a period of time as they tend to hide an exchange of species. On the other hand, it is possible that using importance values (IV's) as a comparison procedure may be overly sensitive and emphasize short term (yearly?) changes within a system. Long term studies comparing the results of the two methods may help to define the differences.

3. The results of this study showed that annual species are opportunistic in distribution. Therefore, annual species are not recommended for use as indicators of persistent, long term changes in a vegetation pattern. On the other hand, perennial species were more consistent in their distribution pattern. Perennials would, therefore, provide good evidence for persistent long term changes.

4. The increased importance value of the salt tolerant species Spartina cynosuroides suggest that the vegetation of Sweet Hall Marsh shifted toward oligohaline species. The presence of levee's in Sweet Hall Marsh further supports the hypothesis that Sweet Hall Marsh is currently undergoing a transition to an oligohaline system.

5. The use of aerial photography to determine temporal and spatial vegetation changes on a low resolution were not as productive as had been hoped for in this study. However, most of the problems encountered in this study may be avoided by establishing a easily delineated wetland-upland baseline. One must also realize that most of the available historical aerial photographs were taken for agricultural purposes. In most cases, they were flown during leaf off, i.e. during winter and/or very early spring. Many wetland species, particularly those that are nonpersistent, would not appear on the photographs. Persistent species, such as Spartina cynosuroides, do have recognizable

signatures. In Sweet Hall Marsh, comparison of recognizable signatures did not indicate that the changes in vegetation associations were occurring in a linear fashion.

6. Of special interest: *Carex hyalinolepis*, a species of which little is known, has been shown to be a high marsh species in Sweet Hall Marsh. It has an inundation tolerance less than that of *Spartina cynosuroides*.

LITERATURE CITED

Adams, D.A. 1963. Factors influencing vascular plant zonation in North Carolina salt marshes. Ecology 44:445-456.

Anderson, R.R., R.G. Brown, and R.D. Rappleye. 1968. Water quality and plant distribution along the upper Patuxent River, Maryland. Chesapeake Sci. 9(3):145-156.

Barco, J.W. and R.M. Smart. 1981. Sediment based nutrition of submersed macrophytes. Aquatic Bot. 10:339-352.

Barnett, T.P. 1983. Global sea level: estimating and explaining apparent change. In Coastal Zone 83. O.T. Morgan, editor. New York Am. Soc. Civil Eng. pp. 2777-2795.

Boon, III, J.D. 1988. Personal communications. Virginia Institute of Marine Science, School of Marine Science, College of William and Mary,, Gloucester Point, Va.

_____. 1978. Suspended solids transport in a salt marsh creek-an analysis of errors. In Estuarine transport processes. B. Kjerfve (ed). Univ. South Carolina Press, Columbia, S.C. p.147-159.

_____, and K.P. Kiley. 1978. Harmonic analysis and tidal prediction by the method of least squares. Special Report No. 186, Virginia Inst. Mar. Sci., 49p.

_____, and M.P. Lynch. 1972. Tidal datum planes and tidal boundaries and their use as legal boundaries. SR No. 22. Virginia Institute of Marine Sci., School of Marine Sci., College of William and Mary, Gloucester Point, Va.

Booth, P.M. 1989. Nitrogen and phosphorus cycling stratigies in two tidal freshwater macrophytes, *Peltandra virginia* and *Spartina cynosuroides*. Dissertation. Virginia Institute of Marine Sci., School of Marine Sci., College of William and Mary, Gloucester Point, Va.

Bradshaw, J.G. and A.Y. Kuo. 1987. Salinity distribution in the James River estuary. SR 292. Virginia Institute of Marine Sci., School of Marine Sci., College of William and Mary, Gloucester Point, Va.

Broadfoot, W.M. and H.L. Williston. 1973. Flooding effects on southern forests. J. Forestry, 71(9):584-587.

Brooks, T.J. 1983. Pamunkey River slack water data report: temperature, salinity, dissolved oxygen. 1970-1980. VIMS Data Report #20. Virginia Institute of Marine Sci., School of Marine Sci., College of William and Mary, Gloucester Point, Va.

Chapin, III, F.S. 1980. The mineral nutrition of wild plants. Ann. Rev. Ecol. Sys. 11:233-260.

Chapman, V.J. 1960. Salt marshes and salt deserts of the world. Interscience, New York. 392p.

_____. 1974. Salt marshes and salt deserts of the world. In Ecology of halophytes. R.J. Reimold and W.H. Queens (eds). Academic Press, New York. p.3-19.

_____. 1975. The salinity problem in general: its importance and distribution with special reference to natural halophytes. In Plants in saline environments. A. Poljakoff-Mayber and J. Gale (eds). Ecological Studies No. 15. Springer-Verlag, New York. p.7-24.

Cook, G.H. 1857. On the subsidence of the land on the sea coast of New Jersey and Long Island. Am. J. Sci. 74:341-354.

Cronquest, A. 1981. An integrated system of classification of flowering plants. Columbia University Press, New York. 1262 p.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. Publ. No. FWS/OB-79/31. US Fish and Wildlife Service, Washington, DC. 103p.

Curtis, J.T. and R.P. McIntosh. 1950. The interrelations of certain analytical and synthetic phytosociological characters. Ecol. 31: 434-455.

Daubenmire, R.F. 1959. Canopy coverage methods of vegetation analysis. Northwest Sci. 33:43-64.

_____. 1966. Vegetation: identification of typical communities. Sci. 151:291-298.

_____. 1968. Plant communities: a text book of plant synecology. Harper and Row, New York.

Davis, C.A. 1911. Salt marshes, a study in correlation. Assoc. Am. Geol. I. p.139-143.

Delaune, R.D., R.H. Bauman, and J.G. Gosselink. 1986. Relationships among vertical accretion, coastal submergence and erosion in a Louisiana Gulf Coast marsh. J. Sediment. Petrol. 53:147-157.

Dott, Jr., R.H. 1983. Episodic sedimentation-how normal is average? How rare is rare? Does it matter? J. Sedim. Petrol. 53:5-23.

_____. 1988. An episodic view of shallow marine clastic sedimentation. in de Boer, P.L., A. van Gelder, and S.D. Nio (eds). Tidal-influenced sedimentary environments and facies. Reidel Pub. Co., Boston. 530p.

Doumlele, D.G., 1976. Primary production and plant community structure in a tidal freshwater marsh. Master Thesis, Virginia Institute of Marine Science, School of Marine Science, College of William and Mary,, Gloucester Point, Va.

_____. 1981. Primary production and seasonal aspects of emergent plants in a tidal freshwater marsh. Estuaries 4(2):139-142.

Environmental Protection Agency. 1983. Chesapeake Bay: a profile of environmental change. U.S. EPA Chesapeake Bay Program. Annapolis MD.

_____. 1987. Greenhouse effect , sea level rise and coastal wetlands. J.G. Titus, editor. U.S. EPA, Office of Planning and evaluation, Wash., D.C.

Evans, D. 1989. Personal communications. Virginia Institute of Marine Science, School of Marine Science, College of William and Mary,, Gloucester Point, Va.

Frey, R.W. and P.B. Basan, 1976. Coastal salt marshes. In Davis, Jr., R.A. (ed). Coastal sedimentary environments. 1st. edition. Springer-Verlag, New York.

_____. 1985. Coastal salt marshes. In Davis, Jr., R.A. (ed). Coastal sedimentary environments. 2nd edition. Springer-Verlag, New York.

Froomer, N.L. 1980a. Morphological changes in some Chesapeake Bay tidal marshes resulting from accelerated soil erosion. Z. Geomorph. N.F. 34:242-254.

_____. 1980b. Sea level changes in the Chesapeake Bay during historic times. Mar. Geol. 36:289-305.

Gambrel, R.P. and W.H. Patric, 1978. Chemical and microbiological properties of anaerobic soils and sediment. In Hook, D.D. and R.M.M. Crawford (eds). Plant life in anaerobic environments. Ann Arbor Science Publ.

Garbisch, E.W., Jr., P.B. Woller, and R.J. McCallum. 1975. Salt marsh establishment and development. Tech. Memo. No. 52. U.S. Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va. 110p.

Gleason, H.A. 1952. The new Brittan and Brown illustrated flora of the Northeastern United States and Canada. Vol. 1. The pteridophyta, gymnospermae, and monocotyledoneae. Hafner Press, New York. 480p.

Gleason, M.L., D.H. Elmer, N.C. Pien, and J.S. Fisher. 1979. Effects of stem density upon sediment retention by salt marsh cord grass, Spartina alterniflora Loisel. Estuaries 2:271-273.

Gornitz, V., S. Lebedeff, and J. Hansen. 1982. Global sea level trends in the past century. Sci. 215:1611-1614.

Gray, A.J. and R.G.H. Bunce. 1972. The ecology of Morcamby Bay. VI. Soils and vegetation of the salt marshes: a multivariate approach. J. Appl. Ecol. 9:221-234.

_____ and R. Scott. 1977. The ecology of Morcamby Bay. VII. The distribution of Puccinellia maritima, Festuca rubra, and Agrostis stolonifera in the salt marshes. J. Appl. Ecol. 14:229-241.

Greenwood, D.J. 1961. The effect of oxygen concentration on the decomposition of organic materials in soil. Plant and Soil 14:360-376.

Gross, L.J. 1980. Biophysical ecology: an introduction to organism response to environment. in Hallam, T.G. and S.A. Levin. (eds). Mathematical ecology: an introduction. Springer-Verlag, New York. p.1-36.

_____. 1986. Biophysical ecology: an introduction to organism response to environment. In Mathematical ecology: an introduction. T.G. Hallam and S.A. Levin (eds). p.19-34.

Hammer, D.E. and R.H. Kadlec. 1983. Design principles for wetland treatment systems. U.S. Environmental Protection Report EPA-600/2-83-026. Washington, D.C.

Hicks, S.D. 1972. On the classification and trends of long period sea level series. Shore and Beach 40:20-23.

_____. 1972. An average geopotential sea level series for the United States. J. Geophysical Res. 83(C3):1377-1379.

Hobbs, C.H. III, M.H. Peoples, G.L. Anderson and P. Rosen. 1975. Shoreline situation report: New Kent, King William, and King and Queen Counties. Virginia Institute of Marine Sci., Gloucester Point, Va. 89 p.

Holdahl, S.R. and N.L. Morrison. 1974. Regional investigations of vertical crustal relevelings and mareograph data. Tectonophysics 23:373-390.

Hofner, R., L. Vasquez-Moreno, K. Winter, H.J. Bohnert, and J.M. Schmitt. 1987. Induction of crassulacean acid metabolism in Mesembryanthemum crystallinum by high salinity: mass increase and de novo synthesis of PEP-carboxylase. Plant Physiol. 83:915-919.

Horn, W., 1960. Some recent approaches to tidal problems. Int. Hydrographic Review, vol. XXXVIII, Monaco, pp.65-84.

Jervis, R.A. 1969. Primary production in the freshwater ecosystem of Troy Meadows, New Jersey. Bull. Torrey Bot. Club 96: 209-231.

Johnson, D.W. 1925. The New England Acadian shoreline. Hafner Pub. Co. New York. 608p.

_____, and H.H. York. 1915. The relationship of plants to tide-levels: a study of factors affecting the distribution of marine plants. Carnegie Institution, Washington, D.C. 162p.

Kadlec, J.A. and W.A. Wentz. 1974. State-of-the-art survey and evaluation of marsh plant establishment techniques: induced and natural. U.S. Army Coastal Engineering Research Center, Ft. Belvoir, Virginia.

Knauss, J.A. 1978. Introduction to physical oceanography. Prentice-Hall, Inc. Englewood Cliffs, New Jersey. 338p.

Knight, J.B. 1934. A salt marsh study. Am. J. Sci., Sec. 5. 28:161-181.

Kontkanen, P. 1957. On the delineation of communities on research on animal biocoenotics. Cold Springs Harbor Sym. Quant. Biol. 22:373-378.

Ledwin, J.M. 1988. Sedimentation and its role in the nutrient dynamics of a tidal freshwater marsh. Unpublished Masters Thesis, The School of Marine Sci., The College of William and Mary, Gloucester Point, Va.

Mahall, B.E. and, R.B. Park. 1976. The ecotone between Spartina foliosa Trin. and Salicornia virginica L. in salt marshes of northern San Francisco Bay. II. Soil and water salinity. J. Ecol. 64:793-809.

Mendelsshon, I.A. 1979. Nitrogen metabolism in the height forms of Spartina alterniflora in North Carolina. Ecology 60:574-584.

Michalowski, C.B., J.M. Schmitt, and H.J. Bohnert. 1989. Expression during salt stress and nucleotide sequence of cDNA for ferredoxin-$NADP^+$ reductase from Mesembryanthemum crystallinum. Plant Physiol. 89:817-822.

Mitsch, W.J. and J.G. Gosselink. 1986. Wetlands. Van Nostrand Reinhold Co., N.Y. 539p.

Mooring, M.T., A.W. Cooper, and E.D. Seneca. 1971. Seed germination response and evidence for height ecophenes in Spartina alterniflora from North Carolina. Am. J. Bot. 58:48-55.

Mudge, B.F. 1862. The salt marsh formations of Lynn. Proceedings Essex Inst., Vol. II: 1856-1860. Salem, Mass.

Mueller-Dombois, D. and H. Ellenberg. 1974. Aims and methods of vegetation ecology. John Wiley & Sons, Inc., New York.

National Cooperative Soil Survey. 1980. Soil survey of Gloucester Co., Va. U.S. Dept. Ag., Soil Conservation Service, Washington, D.C. 88 p.

Niering, W.A. and R.S. Warren. 1980. Vegetation patterns and processes in New England salt marshes. BioSci. 30(5):301-307.

Nester, J. 1977. Interstitial salinity as a cause of ecophenic variation in Spartina alterniflora. Estuarine Coastal Mar. Sci. 5:707-714.

Nixon, S.W. 1980. Between coastal marshes and coastal waters-a review of twenty years of speculation and research on the role of salt marshes in estuarine productivity and water chemistry. In Estuarine and wetland processes. P. Hamilton and K.B. MacDonald (eds). Plenum, New York. p.437-525.

Odum, E.P. 1960. Organic production and turnover in old field succession. Ecol. 41:34-39.

Odum, W.E. 1988. Comparative ecology of tidal freshwater marshes and salt marshes. Ann. Rev. Syst. 19:147-176.

_____ and M.E. Haywood. 1978. Decomposition of intertidal freshwater marsh plants. In Freshwater wetlands: ecological processes and management potential. R.E. Good, D.G. Whigham, and R.L. Simpson (eds). Academic Press, New York. p.89-97

_____, T.J. Smith III, J.K. Hoover, and C.C. McIvor. 1984. The ecology of tidal freshwater marshes of the United States east coast: a community profile. U.S. Fish Wildl. Serv. FWS/OBS-83/17. Wash., D.C. 177 pp.

Oertel, G.F., G.T.F. Wong and J.D. Conway. 1989. Sediment accumulation at a fringe marsh during transgression. Estuaries 12(1):18-26.

Orson, R., W. Panageotou, and S.P. Leatherman. 1985. Response of tidal salt marshes of the U.S. Atlantic and Gulf Coasts to rising sea levels. J. Coastal Res. 1(1):29-37.

Ostrem, J.A., S.W. Olson, J.M. Schmitt, and H.J. Bohnert. 1987. Salt stress increases the level translatable mRNA for phosphoenolpyruvate carboxylase in *Mesembryanthemum crystallinum*. Plant Physiol. 84:1270-1275.

Ovenshine, T., D.C. Lawson, and S.R. Bartsch-Winkler. 1976. The Placer River silt; an intertidal deposit caused by the 1964 Alaska earthquake. J. Res. U.S. Geol. Surv. 4:151-162.

Penthick, J.S. 1980. Salt-marsh initiation during the holocene transgression: the example of the North Norfolk marshes, England. J. Biogeo. 7:1-9

Phillip, C.C. and R.G. Brown. 1965. Ecological studies of the transition-zone vascular plants in South River, Maryland. Ches. Sci. 6(2):73-81

Phillips, E.A. 1959. Methods of vegetation study. Holt, New York. 107 p.

Postma, H. 1967. Sediment transport and sedimentation in the estuarine environment. In Estuaries. G.H. Lauff (ed). Am. Assoc. Advan. Sci., Washington, D.C. p.158-179.

Radford, A.E., H.E. Ahles, and R.E. Bell. 1968.Manual of the vascular flora of the Carolinas. Univ. North Carolina Press, Chapel Hill, NC.

Ranwell, D.S. 1964. Spartina marshes in southern England. II Rate and seasonal patterns of sediment accretion. J. Ecol. 52:79-94.

Reay. 1989. Virginia Institute of Marine Sci., School of Marine Sci., College of William and Mary, Gloucester Point, Va.

Redfield, A.C. 1959. The Barnstable Marsh. Proc. Salt Marsh Conference, Marine Institute, Univ. Georgia. p.37-39.

_____. 1967a. The ontogeny of a salt marsh estuary. In G.H. Lauff (ed). Estuaries. Pub. No. 83. AAAS. p.108-114.

_____. 1967b. Postglacial change in sea level in the western North Atlantic Ocean. Sci. 157:687-691.

_____. 1972. Development of a New England salt marsh. Ecol. Mono. 42:201-237.

_____ and M. Ruben. 1962. The age of salt marsh peat and its relation to recent changes in sea level at Barnstable, Massachusetts. Proc. Nat. Acad. Sci. 48(10):1728-1735.

Reed, P.R. 1988. National list of plant species that occur in wetlands: 1988, Virginia. National Wetlands Inventory, U.S. Fish and Wildlife Service, St. Petersburg, Florida.

Reimold, R.J. and W.M. Queen (eds). 1974. Ecology of halophytes. Academic Press, New York.

Roberts, D.T. 1976. The effects of nitrogen and iron enrichments on Spartina alterniflora on two Connecticut tidal marshes. Unpublished Masters Thesis, Connecticut College, New London, Ct.

Rykiel, E.J., Jr. 1984. General hydrology and mineral budgets for Okefenoke Swamp: ecological significance. In The Okefenoke Swamp: its natural history, geology, and geochemistry. A.D.

Cohen, D.J. Casagrande, M.J. Andrejko, and G.R. Best (eds.). Wetland Surveys, Los Alamos, New Mexico. pp.218-228.

Schureman, P. 1958. Manual of harmonic analysis and prediction of tides. Special Pub. No.98. U.S. Dept. of Commerce, Coast and Geodetic Survey, Wash., D.C. 317p.

Shaler, N.S. 1885. Sea coast swamps of the eastern United States. U.S. Geological Survey, 6th Annual Report. p.359-375.

Shannon, C.E. and W. Weaver. 1949. The mathematical theory of communication. University of Il. Press, Urbana, Il. 117 p.

Simpson, R.L., R.E. Good, M.A. Leck, and D.F. Whigham. 1983. The ecology of freshwater tidal wetlands. BioSci. 33(): 255-259.

Sklar, F.H., R. Costanza and J.W. Day, Jr. 1985. Dynamic spatial simulation modeling of coastal wetland habitat succession. Ecol. Mod. 29: 261-281.

Snow, A.A. and S.W. Vince. 1984. Plant zonation in an Alaskan salt marsh. II. An experimental study of the role of edaphic conditions. J. Ecol. 72:669-684.

Sokal, R.R. and P.H.A. Sneath. 1963. Principles of numerical taxonomy. W.H. Freeman, San Francisco. 359 p.

Stevenson, J.C., L.G. Ward, and M.S. Kearney. 1986. Vertical accretion rates in marshes with varying rates of sea level rise. In Wolf, D.A. (ed). Estuarine variability. Academic Press. p.241-259.

_____, L.G. Ward, and M.S. Kearney. 1990. Sediment transport and trapping in marsh systems: implications of tidal flux studies. in press: Marine geology.

Teal, J.M. 1962. Energy flow in the salt marsh ecosystem of Georgia. Ecology 43:614-624.

Teskey, R.O. and T.M. Hinckley. 1980. Impact of water level changes on woody riparian and wetland communities. Vol. 1. Plant and soil response. FWS/OBS-77/58. Office of Biological Services, Fish and Wildlife Service, U.S. Dept. of the Interior, Washington, D.C.

Tiner, R.W. Jr. 1987. Mid-Atlantic wetlands: a disappearing natural treasure. U.S. Dept. of the Interior, Fish and Wildlife Ser., Region 5, Newton Corner, Ma. 28p.

U.S. Dept. of Commerce. 1987. Tide Tables 1988: high and low water predictions-East Coast of North and South America including Greenland. U.U. Dept. of Comm., National Oceanic and Atmospheric Administration, National Ocean Service., Washington, D.C. 288 p.

Valiela, I., J.M. Teal, and W.G. Deuser. 1978. The nature of the growth forms in salt marsh grass Spartina alterniflora. Am. Nat. 112:461-470.

Vernon, D.M., J.A. Ostrem, J.M. Schmitt, and H.J. Bohnert. 1988. PEP-case transcript levels in Mesembryanthemum crystallinum decline rapidly upon relief from salt stress. Plant Physiol. 86:1002-1004.

Vince, S.W. and A.A. Snow. 1984. Plant zonation in an Alaskan salt marsh. I. Distribution, abundance, and environmental factors. J. Ecol. 72:651-667.

Wetzel, R.L. and H.A. Neckles. 1986. A model of Zostera marina L. photosynthesis and growth: simulated effects of selected physical-chemical variables and biological interactions. Aquatic Bot. 26:307-323.

Walker, R. 1981. Nitrogen, phosphorus, and production dynamics for Peltandra virginica Knuth in a southern New Jersey freshwater tidal marsh. Dissertation, Rutgers Univ., New Jersey.

Whigham, D.F. and R.L. Simpson. 1976. The potential use of freshwater tidal marshes in the management of water quality in the Delaware River. In Biological control of water pollution. Univ. Penn. Press, Philadelphia.

Whitford, P.B. 1949. Distribution of woodland plants in relation to succession and clonal growth. Ecol. 30: 199-208.

Wohlgemuth, M.A. 1988. Estimation of net aerial primary production of Peltandra virginica using harvest and tagging techniques. M. S. Thesis, Virginia Institute of Marine Sci., School of Marine Sci., College of William and Mary, Gloucester Point, Va.

Woodhouse, W.W. Jr. 1979. Building marshes along the coast of the continental United States. U.S. Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va. Spec. Rept. No. 4. 96p.

APPENDIX I. RELATIVE VEGETATION DATA FOR SWEET HALL MARSH

APRIL, 1987 DATA COMPUTATIONS

SPECIES	FREQ	COVER	DENSITY	RF	RC	RD	IV
7	5	2.6	31	1.190476	0.362571	0.854937	2.407984
8	15	7.8	65	3.571429	1.087714	1.792609	6.451752
10	5	2.6	8	1.190476	0.362571	0.220629	1.773676
11	2.5	0.1	5	0.595238	0.013945	0.137893	0.747076
13	12.5	47.5	306	2.97619	6.623902	8.439051	18.03914
14	30	127.5	100	7.142857	17.77995	2.75786	27.68066
15	2.5	2.5	10	0.595238	0.348626	0.275786	1.21965
20	2.5	0.1	1	0.595238	0.013945	0.027579	0.636762
21	2.5	0.1	14	0.595238	0.013945	0.3861	0.995284
26	87.5	56.3	1342	20.83333	7.851067	37.01048	65.69488
31	100	267.8	404	23.80952	37.34486	11.14175	72.29614
32	2.5	0.1	2	0.595238	0.013945	0.055157	0.66434
34	67.5	56	994	16.07143	7.809232	27.41313	51.29379
35	15	5.4	27	3.571429	0.753033	0.744622	5.069084
39	7.5	45	25	1.785714	6.275275	0.689465	8.750455
44	10	5.2	21	2.380952	0.725143	0.579151	3.685246
45	2.5	2.5	4	0.595238	0.348626	0.110314	1.054179
46	37.5	77.9	257	8.928571	10.8632	7.0877	26.87947
47	2.5	0.1	1	0.595238	0.013945	0.027579	0.636762
49	10	10	9	2.380952	1.394506	0.248207	4.023665
TOTALS 20	420	717.1	3626	100	100	100	300

Species Rich
0.352126

Species Eveness
-0.71231

APRIL ,1987

IV	IP	DIVERSITY
2.407984	0.008027	-0.01682
6.451752	0.021506	-0.03586
1.773676	0.005912	-0.01317
0.747076	0.00249	-0.00648
18.03914	0.06013	-0.07341
27.68066	0.092269	-0.09549
1.21965	0.004066	-0.00972
0.636762	0.002123	-0.00567
0.995284	0.003318	-0.00822
65.69488	0.218983	-0.14444
72.29614	0.240987	-0.14893
0.66434	0.002214	-0.00588
51.29379	0.170979	-0.13115
5.069084	0.016897	-0.02994
8.750455	0.029168	-0.04478
3.685246	0.012284	-0.02347
1.054179	0.003514	-0.00862
26.87947	0.089598	-0.09387
0.636762	0.002123	-0.00567
4.023665	0.013412	-0.02511
300		-0.92674

MAY, 1987 DATA COMPUTATIONS

SPECIES	FREQ	COVER	DENSITY	RF	RC	RD	IV
7	30	28.1	117	5.529954	1.03089	3.463588	10.02443
8	10	5.2	46	1.843318	0.19077	1.361753	3.39584
9	2.5	2.5	2	0.460829	0.091716	0.059207	0.611752
11	45	115.1	306	8.294931	4.222614	9.058615	21.57616
12	2.5	0.1	1	0.460829	0.003669	0.029603	0.494101
13	7.5	42.5	26	1.382488	1.559175	0.769686	3.71135
14	22.5	117.6	77	4.147465	4.31433	2.279455	10.74125
15	7.5	5.1	1	1.382488	0.187101	0.029603	1.599193
19	45	50.3	178	8.294931	1.84533	5.26939	15.40965
20	12.5	10.1	44	2.304147	0.370533	1.302546	3.977227
21	2.5	2.5	38	0.460829	0.091716	1.124926	1.677472
26	77.5	117.9	1140	14.28571	4.325336	33.74778	52.35883
27	7.5	7.5	1	1.382488	0.275149	0.029603	1.68724
31	100	1775	688	18.43318	65.1185	20.36708	103.9188
33	2.5	2.5	4	0.460829	0.091716	0.118413	0.670959
34	30	77.6	293	5.529954	2.846871	8.673771	17.0506
35	20	8	16	3.686636	0.293492	0.473653	4.453781
36	22.5	72.5	47	4.147465	2.65977	1.391356	8.198591
39	7.5	45	20	1.382488	1.650891	0.592066	3.625446
41	2.5	2.5	4	0.460829	0.091716	0.118413	0.670959
43	2.5	2.5	2	0.460829	0.091716	0.059207	0.611752
44	7.5	5.1	19	1.382488	0.187101	0.562463	2.132053
45	2.5	0.1	1	0.460829	0.003669	0.029603	0.494101
46	42.5	185.1	267	7.834101	6.790667	7.904085	22.52885
47	5	2.6	8	0.921659	0.095385	0.236827	1.25387
48	2.5	0.1	1	0.460829	0.003669	0.029603	0.494101
49	12.5	37.5	28	2.304147	1.375743	0.828893	4.508783
58	5	5	1	0.921659	0.183432	0.029603	1.134695
61	5	0.2	2	0.921659	0.007337	0.059207	0.988203
TOTALS 29	542.5	2725.8	3378	100	100	100	300

Spe Richness 0.498963

Spe Eveness 0.656564

MAY, 1987 DATA COMPUTATIONS

SPECIES	IV	IP	DIVERSITY
7	10.02443	0.033415	-0.04932
8	3.39584	0.011319	-0.02203
9	0.611752	0.002039	-0.00549
11	21.57616	0.071921	-0.08222
12	0.494101	0.001647	-0.00458
13	3.71135	0.012371	-0.0236
14	10.74125	0.035804	-0.05178
15	1.599193	0.005331	-0.01212
19	15.40965	0.051366	-0.06623
20	3.977227	0.013257	-0.02489
21	1.677472	0.005592	-0.01259
26	52.35883	0.174529	-0.13232
27	1.68724	0.005624	-0.01265
31	103.9188	0.346396	-0.15949
33	0.670959	0.002237	-0.00593
34	17.0506	0.056835	-0.07078
35	4.453781	0.014846	-0.02714
36	8.198591	0.027329	-0.04273
39	3.625446	0.012085	-0.02318
41	0.670959	0.002237	-0.00593
43	0.611752	0.002039	-0.00549
44	2.132053	0.007107	-0.01527
45	0.494101	0.001647	-0.00458
46	22.52885	0.075096	-0.08444
47	1.25387	0.00418	-0.00994
48	0.494101	0.001647	-0.00458
49	4.508783	0.015029	-0.0274
58	1.134695	0.003782	-0.00916
61	0.988203	0.003294	-0.00818
	300		-1.00403
TOTALS			

JUNE, 1987 DATA COMPUTATIONS

SPECIES	FREQ	COVER	DENSITY	RF	RC	RD	IV
7	14.28571	0.1	2	2.857143	0.015793	0.430108	3.303043
11	28.57143	2.6	5	5.714286	0.410613	1.075269	7.200167
14	71.42857	35.1	45	14.28571	5.543272	9.677419	29.50641
26	85.71429	62.6	147	17.14286	9.886292	31.6129	58.64205
31	100	432.5	175	20	68.30385	37.63441	125.9383
33	14.28571	2.5	3	2.857143	0.39482	0.645161	3.897124
34	42.85714	2.7	6	8.571429	0.426406	1.290323	10.28816
35	14.28571	15	3	2.857143	2.36892	0.645161	5.871224
46	42.85714	55	43	8.571429	8.686039	9.247312	26.50478
47	14.28571	2.5	1	2.857143	0.39482	0.215054	3.467017
49	14.28571	2.5	2	2.857143	0.39482	0.430108	3.68207
53	42.85714	17.6	17	8.571429	2.779533	3.655914	15.00688
56	14.28571	2.5	16	2.857143	0.39482	3.44086	6.692823
TOTALS 13	500	633.2	465	100	100	300	300

Spe Richness
0.5903

Spe. Evenness
0.722972

JUNE, 1987 DATA COMPUTATIONS

SPECIES	IV	IP	DIVERSITY
7	3.303043	0.01101	-0.02156
11	7.200167	0.024001	-0.03888
14	29.50641	0.098355	-0.09906
26	58.64205	0.195474	-0.13857
31	125.9383	0.419794	-0.15825
33	3.897124	0.01299	-0.0245
34	10.28816	0.034294	-0.05023
35	5.871224	0.019571	-0.03343
46	26.50478	0.088349	-0.0931
47	3.467017	0.011557	-0.02239
49	3.68207	0.012274	-0.02346
53	15.00688	0.050023	-0.06507
56	6.692823	0.022309	-0.03684
	300	1	-0.80535
TOTALS			

JULY, 1987 DATA COMPUTATIONS

SPECIES	FREQ	COVER	DENSITY	RF	RC	RD	IV
7	40	21.7	104	6.9869	0.680891	3.664553	11.33234
8	15	10.2	58	2.620087	0.32005	2.043693	4.98383
11	52.5	137.6	97	9.170306	4.31754	3.4179	16.90575
12	5	0.2	2	0.873362	0.006275	0.070472	0.95011
13	10	35	254	1.746725	1.098211	8.949965	11.7949
14	22.5	52.8	54	3.930131	1.65673	1.902748	7.48961
15	5	5	10	0.873362	0.156887	0.352361	1.382611
16	2.5	2.5	2	0.436681	0.078444	0.070472	0.585597
19	10	5.2	13	1.746725	0.163163	0.458069	2.367957
20	7.5	5.1	41	1.310044	0.160025	1.444679	2.914748
21	2.5	0.1	2	0.436681	0.003138	0.070472	0.510291
23	7.5	32.5	4	1.310044	1.019768	0.140944	2.470756
24	2.5	0.1	4	0.436681	0.003138	0.140944	0.580763
26	77.5	367.8	1019	13.53712	11.54063	35.90557	60.98332
27	2.5	2.5	2	0.436681	0.078444	0.070472	0.585597
29	2.5	37.5	12	0.436681	1.176655	0.422833	2.036169
30	2.5	2.5	10	0.436681	0.078444	0.352361	0.867486
31	100	1715	684	17.46725	53.81236	24.10148	95.38109
32	15	62.6	29	2.620087	1.96423	1.021846	5.606163
33	15	75.1	6	2.620087	2.356448	0.211416	5.187952
34	45	95.5	95	7.860262	2.996548	3.347428	14.20424
36	15	87.5	47	2.620087	2.745529	1.656096	7.021712
37	2.5	2.5	0	0.436681	0.078444	0	0.515125
39	7.5	20	10	1.310044	0.627549	0.352361	2.289954
40	2.5	2.5	0	0.436681	0.078444	0	0.515125
41	2.5	0.1	2	0.436681	0.003138	0.070472	0.510291
43	2.5	2.5	1	0.436681	0.078444	0.035236	0.550361
44	10	7.6	26	1.746725	0.238469	0.916138	2.901332
45	2.5	2.5	11	0.436681	0.078444	0.387597	0.902722
46	40	295	209	6.9869	9.256354	7.364341	23.60759
47	7.5	7.5	3	1.310044	0.235331	0.105708	1.651083
48	2.5	2.5	4	0.436681	0.078444	0.140944	0.656069
49	7.5	30.1	13	1.310044	0.944462	0.458069	2.712575
52	5	30	3	0.873362	0.941324	0.105708	1.920395
56	7.5	5.1	5	1.310044	0.160025	0.17618	1.646249
57	2.5	2.5	0	0.436681	0.078444	0	0.515125
58	7.5	20	1	1.310044	0.627549	0.035236	1.972829
61	2.5	2.5	0	0.436681	0.078444	0	0.515125
62	2.5	0.1	1	0.436681	0.003138	0.035236	0.475055
TOTALS 39	572.5	3187	2838	100	100	100	300

Spe Rich 0.73208   Spe Even 0.670557

JULY, 1987 DATA COMPUTATIONS

SPECIES	IV	IP	DIVERSITY
7	11.33234	0.037774	-0.05375
8	4.98383	0.016613	-0.02956
11	16.90575	0.056352	-0.07039
12	0.95011	0.003167	-0.00792
13	11.7949	0.039316	-0.05526
14	7.48961	0.024965	-0.04001
15	1.382611	0.004609	-0.01077
16	0.585597	0.001952	-0.00529
19	2.367957	0.007893	-0.0166
20	2.914748	0.009716	-0.01955
21	0.510291	0.001701	-0.00471
23	2.470756	0.008236	-0.01717
24	0.580763	0.001936	-0.00525
26	60.98332	0.203278	-0.14065
27	0.585597	0.001952	-0.00529
29	2.036169	0.006787	-0.01472
30	0.867486	0.002892	-0.00734
31	95.38109	0.317937	-0.15822
32	5.606163	0.018687	-0.0323
33	5.187952	0.017293	-0.03047
34	14.20424	0.047347	-0.06272
36	7.021712	0.023406	-0.03817
37	0.515125	0.001717	-0.00475
39	2.289954	0.007633	-0.01616
40	0.515125	0.001717	-0.00475
41	0.510291	0.001701	-0.00471
43	0.550361	0.001835	-0.00502
44	2.901332	0.009671	-0.01948
45	0.902722	0.003009	-0.00759
46	23.60759	0.078692	-0.08688
47	1.651083	0.005504	-0.01243
48	0.656069	0.002187	-0.00582
49	2.712575	0.009042	-0.01848
52	1.920395	0.006401	-0.01404
56	1.646249	0.005487	-0.01241
57	0.515125	0.001717	-0.00475
58	1.972829	0.006576	-0.01435
61	0.515125	0.001717	-0.00475
62	0.475055	0.001584	-0.00443
TOTALS	300	1	-1.0669

AUGUST, 1987 DATA COMPUTATIONS

SPECIES	FREQ	COVER	DENSITY	RF	RC	RD	IV
7	27.5	13.1	17	4.280156	0.447925	0.526968	5.255049
8	20	15.2	48	3.11284	0.519729	1.487911	5.12048
11	37.5	200.2	105	5.836576	6.845381	3.254805	15.93676
12	2.5	15	1	0.389105	0.512891	0.030998	0.932994
13	15	20.3	150	2.33463	0.694112	4.649721	7.678463
14	22.5	82.5	41	3.501946	2.820899	1.270924	7.593768
15	5	5	9	0.77821	0.170964	0.278983	1.228157
16	7.5	5.1	3	1.167315	0.174383	0.092994	1.434692
18	2.5	0.1	2	0.389105	0.003419	0.061996	0.454521
19	12.5	22.6	25	1.945525	0.772755	0.774954	3.493234
20	22.5	8.1	86	3.501946	0.276961	2.66584	6.444747
21	5	0.2	12	0.77821	0.006839	0.371978	1.157026
23	15	32.8	9	2.33463	1.121521	0.278983	3.735135
26	77.5	477.8	968	12.06226	16.33728	30.0062	58.40573
27	5	5	0	0.77821	0.170964	0	0.949174
29	7.5	102.5	15	1.167315	3.504753	0.464972	5.13704
31	100	570	628	15.5642	19.48984	19.46683	54.52088
32	12.5	10.1	9	1.945525	0.345346	0.278983	2.569855
33	35	202.6	16	5.447471	6.927443	0.49597	12.87088
34	30	57.9	31	4.669261	1.979758	0.960942	7.609961
35	2.5	2.5	0	0.389105	0.085482	0	0.474587
36	17.5	90	47	2.723735	3.077344	1.456913	7.257992
39	7.5	20	9	1.167315	0.683854	0.278983	2.130153
41	2.5	2.5	4	0.389105	0.085482	0.123993	0.598579
43	2.5	0.1	1	0.389105	0.003419	0.030998	0.423522
44	10	2.8	6	1.55642	0.09574	0.185989	1.838149
45	7.5	5.1	46	1.167315	0.174383	1.425914	2.767612
46	40	290	163	6.225681	9.915886	5.052697	21.19426
47	2.5	2.5	0	0.389105	0.085482	0	0.474587
48	2.5	2.5	4	0.389105	0.085482	0.123993	0.598579
49	10	7.6	6	1.55642	0.259865	0.185989	2.002274
51	2.5	15	29	0.389105	0.512891	0.898946	1.800942
53	62.5	627.9	730	9.727626	21.4696	22.62864	53.82587
56	2.5	2.5	1	0.389105	0.085482	0.030998	0.505585
57	2.5	2.5	0	0.389105	0.085482	0	0.474587
58	2.5	2.5	1	0.389105	0.085482	0.030998	0.505585
60	2.5	2.5	4	0.389105	0.085482	0.123993	0.598579
TOTALS 37	642.5	2924.6	3226	100	100	100	300

Spe Rich 0.651433

Spec Evenness 0.723529

AUGUST, 1987 DATA COMPUTATIONS

SPECIES	IV	IP	DIVERSITY
7	5.255049	0.017517	-0.03077
8	5.12048	0.017068	-0.03017
11	15.93676	0.053123	-0.06772
12	0.932994	0.00311	-0.0078
13	7.678463	0.025595	-0.04074
14	7.593768	0.025313	-0.04042
15	1.228157	0.004094	-0.00978
16	1.434692	0.004782	-0.0111
18	0.454521	0.001515	-0.00427
19	3.493234	0.011644	-0.02252
20	6.444747	0.021482	-0.03583
21	1.157026	0.003857	-0.00931
23	3.735135	0.01245	-0.02372
26	58.40573	0.194686	-0.13836
27	0.949174	0.003164	-0.00791
29	5.13704	0.017123	-0.03025
31	54.52088	0.181736	-0.13459
32	2.569855	0.008566	-0.01771
33	12.87088	0.042903	-0.05867
34	7.609961	0.025367	-0.04048
35	0.474587	0.001582	-0.00443
36	7.257992	0.024193	-0.0391
39	2.130153	0.007101	-0.01526
41	0.598579	0.001995	-0.00539
43	0.423522	0.001412	-0.00402
44	1.838149	0.006127	-0.01356
45	2.767612	0.009225	-0.01877
46	21.19426	0.070648	-0.08131
47	0.474587	0.001582	-0.00443
48	0.598579	0.001995	-0.00539
49	2.002274	0.006674	-0.01452
51	1.800942	0.006003	-0.01334
53	53.82587	0.17942	-0.13387
56	0.505585	0.001685	-0.00467
57	0.474587	0.001582	-0.00443
58	0.505585	0.001685	-0.00467
60	0.598579	0.001995	-0.00539
TOTALS	300	1	-1.13464

SEPTEMBER, 1987 DATA COMPUTATIONS

SPECIES	FREQ	COVER	DENSITY	RF	RC	RD	IV
14	20	2.6	4	5.128205	0.597152	0.613497	6.338854
19	30	15.2	14	7.692308	3.491043	2.147239	13.33059
26	50	37.5	109	12.82051	8.61277	16.71779	38.15107
31	100	122.5	188	25.64103	28.13505	28.83436	82.61043
34	20	2.6	4	5.128205	0.597152	0.613497	6.338854
36	20	5	8	5.128205	1.148369	1.226994	7.503568
39	20	5	5	5.128205	1.148369	0.766871	7.043446
46	50	60	53	12.82051	13.78043	8.128834	34.72978
53	80	185	267	20.51282	42.48966	40.95092	103.9534
TOTALS 9	390	435.4	652	100	100	100	300

- Spe Rich
0.351928

Spe Evenness
0.780955

SEPTEMBER, 1987

IV	IP	DIVERSITY
6.338854	0.02113	-0.03539
13.33059	0.044435	-0.06009
38.15107	0.12717	-0.1139
82.61043	0.275368	-0.15423
6.338854	0.02113	-0.03539
7.503568	0.025012	-0.04007
7.043446	0.023478	-0.03825
34.72978	0.115766	-0.10841
103.9534	0.346511	-0.15949
300	1	2
		-0.74522

OCTOBER, 1987 DATA COMPUTATIONS

SPECIES	FREQ	COVER	DENSITY	RF	RC	RD	
11	10	2.6	0	2.857143	0.65261	0	3.5
13	5	2.5	2	1.428571	0.62751	0.247831	2.3
14	40	140	116	11.42857	35.14056	14.37423	60.
19	15	5.1	4	4.285714	1.28012	0.495663	6.0
20	5	0.1	1	1.428571	0.0251	0.123916	1.5
26	65	52.7	357	18.57143	13.22791	44.23792	76.
31	100	70.2	190	28.57143	17.62048	23.54399	69
32	10	5	1	2.857143	1.25502	0.123916	4.2
34	15	20	4	4.285714	5.02008	0.495663	9.8
46	40	42.6	44	11.42857	10.69277	5.452292	27.
53	45	57.6	88	12.85714	14.45783	10.90458	38.
TOTALS	350	398.4	807	100	100	100	
11							

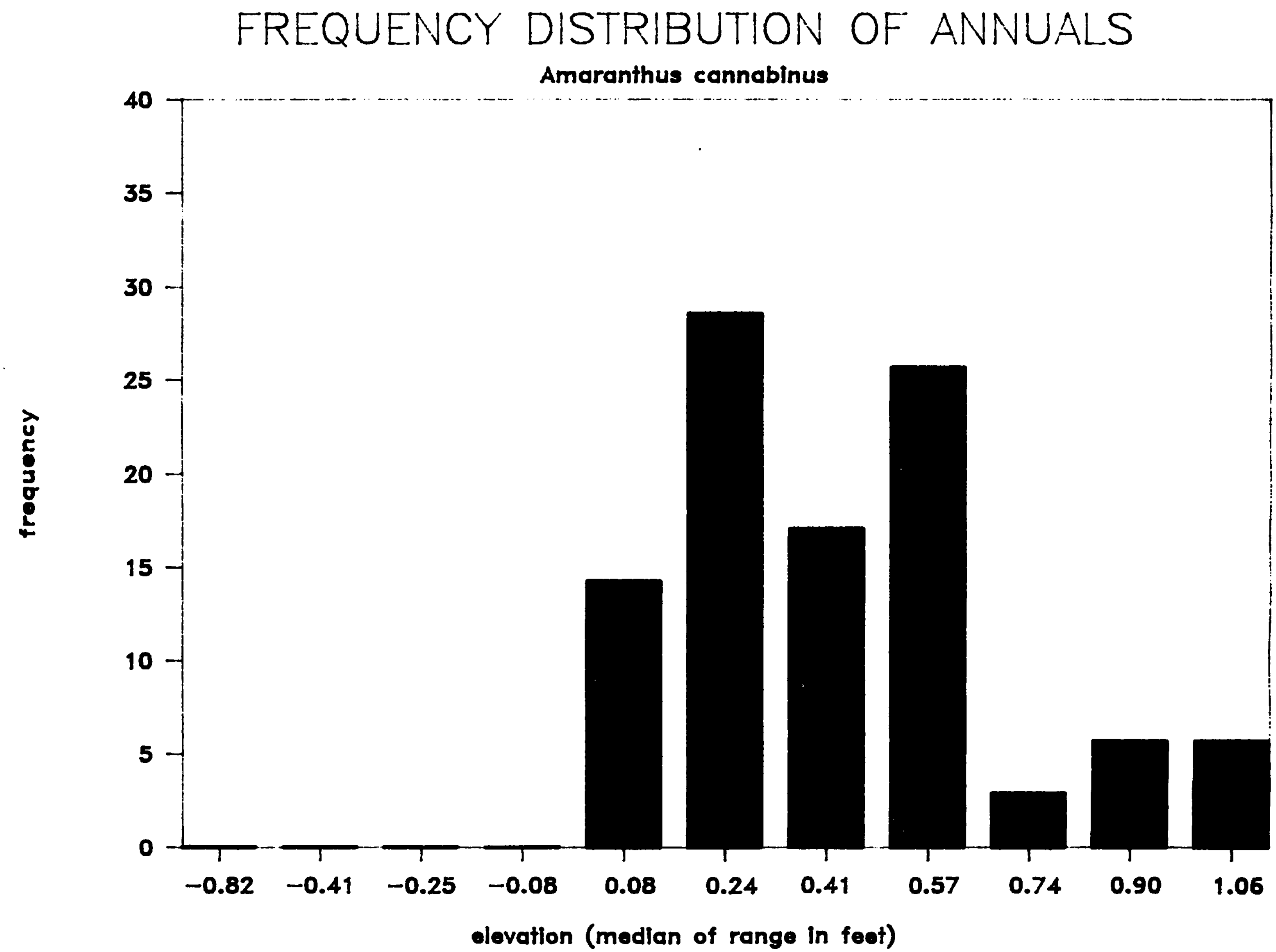
Spe Rich
0.387218

Spe Evenness
0.775894

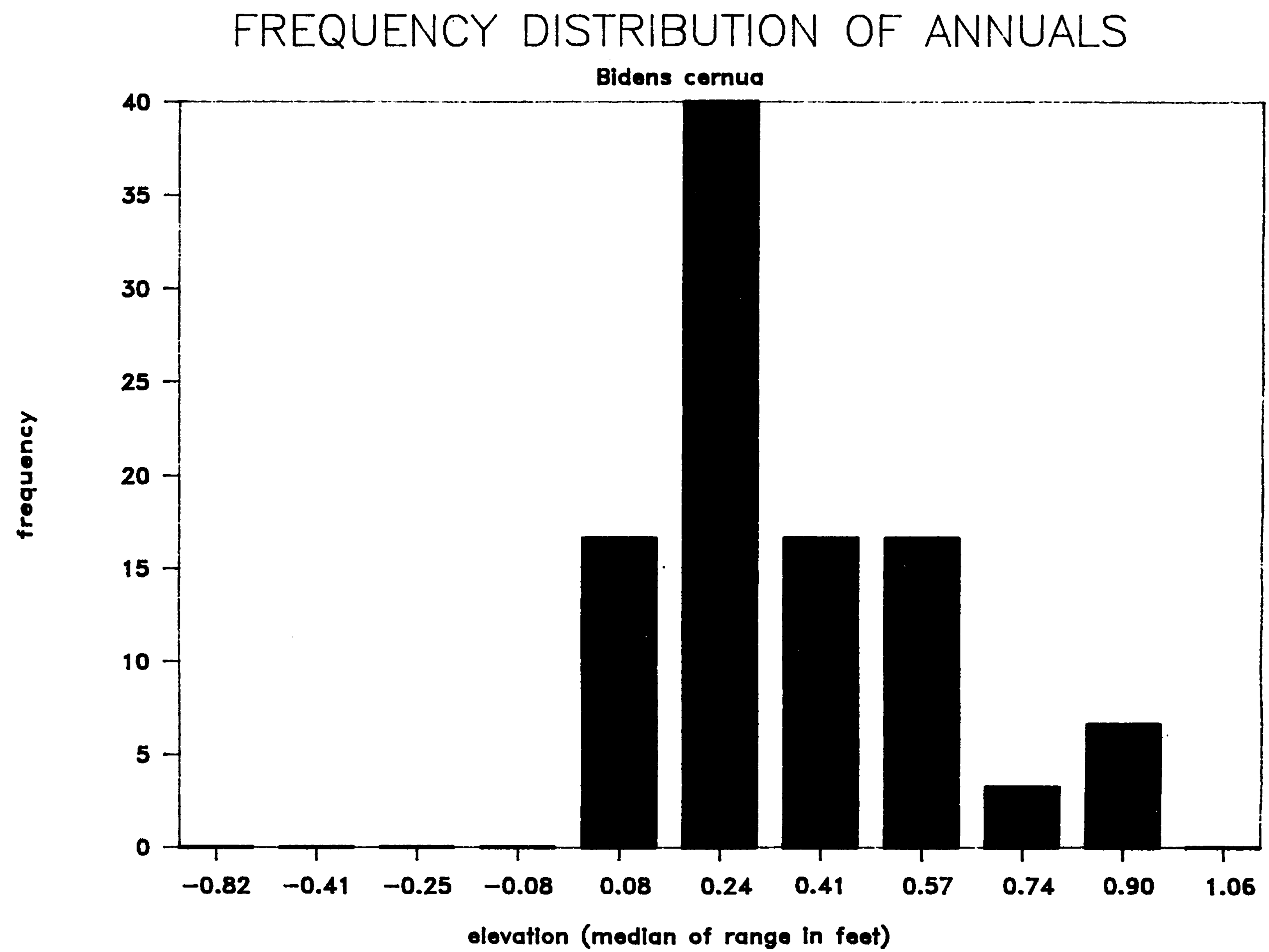
OCTOBER, 1987 DATA COMPUTATIONS

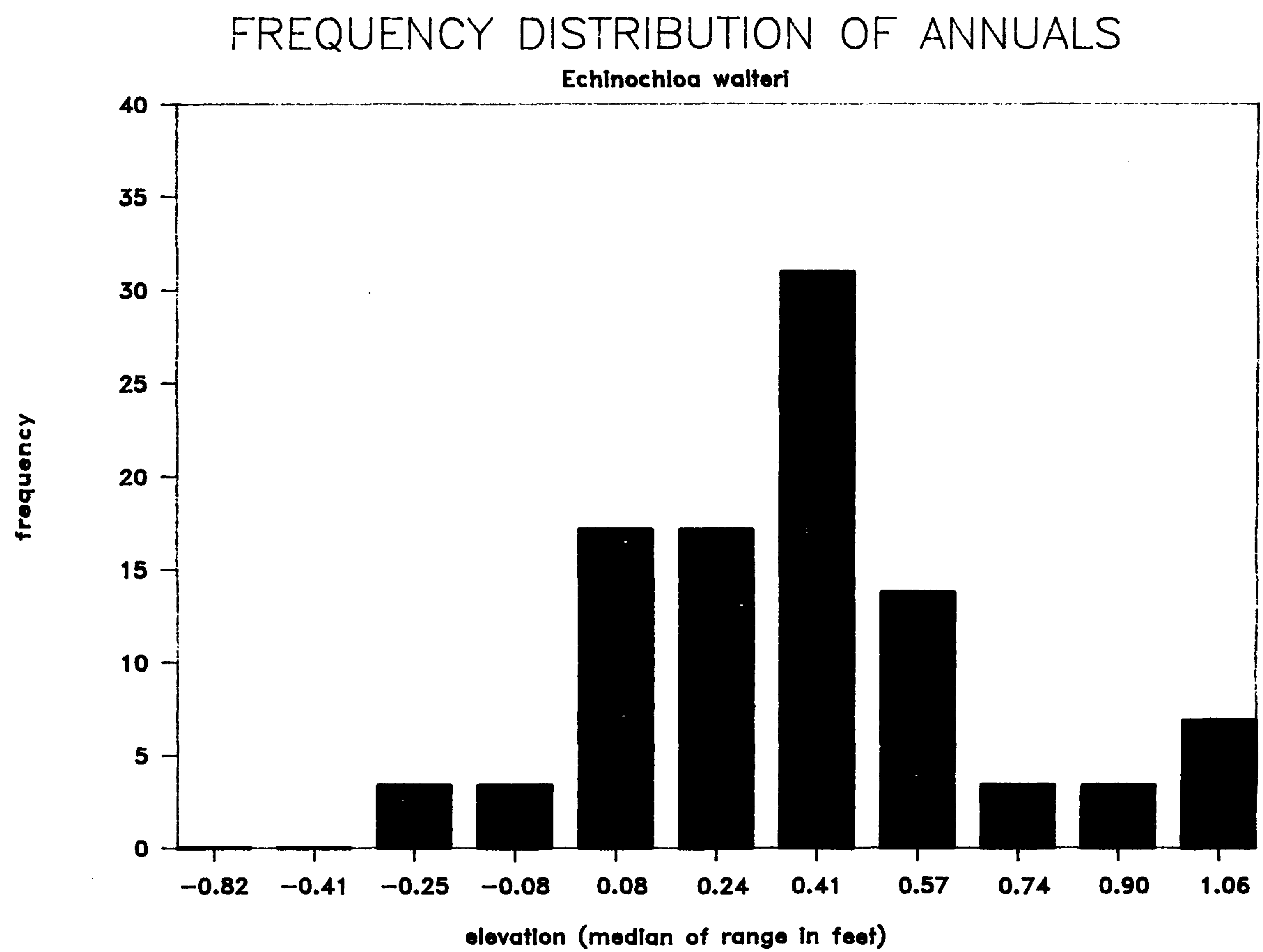
SPECIES	IV	IP	DIVERSITY
11	3.509753	0.011699	-0.0226
13	2.303913	0.00768	-0.01624
14	60.94336	0.203145	-0.14062
19	6.061498	0.020205	-0.03424
20	1.577588	0.005259	-0.01199
26	76.03726	0.253458	-0.15108
31	69.7359	0.232453	-0.1473
32	4.236079	0.01412	-0.02612
34	9.801458	0.032672	-0.04854
46	27.57363	0.091912	-0.09528
53	38.21956	0.127399	-0.114
TOTALS	300	1	-0.80801

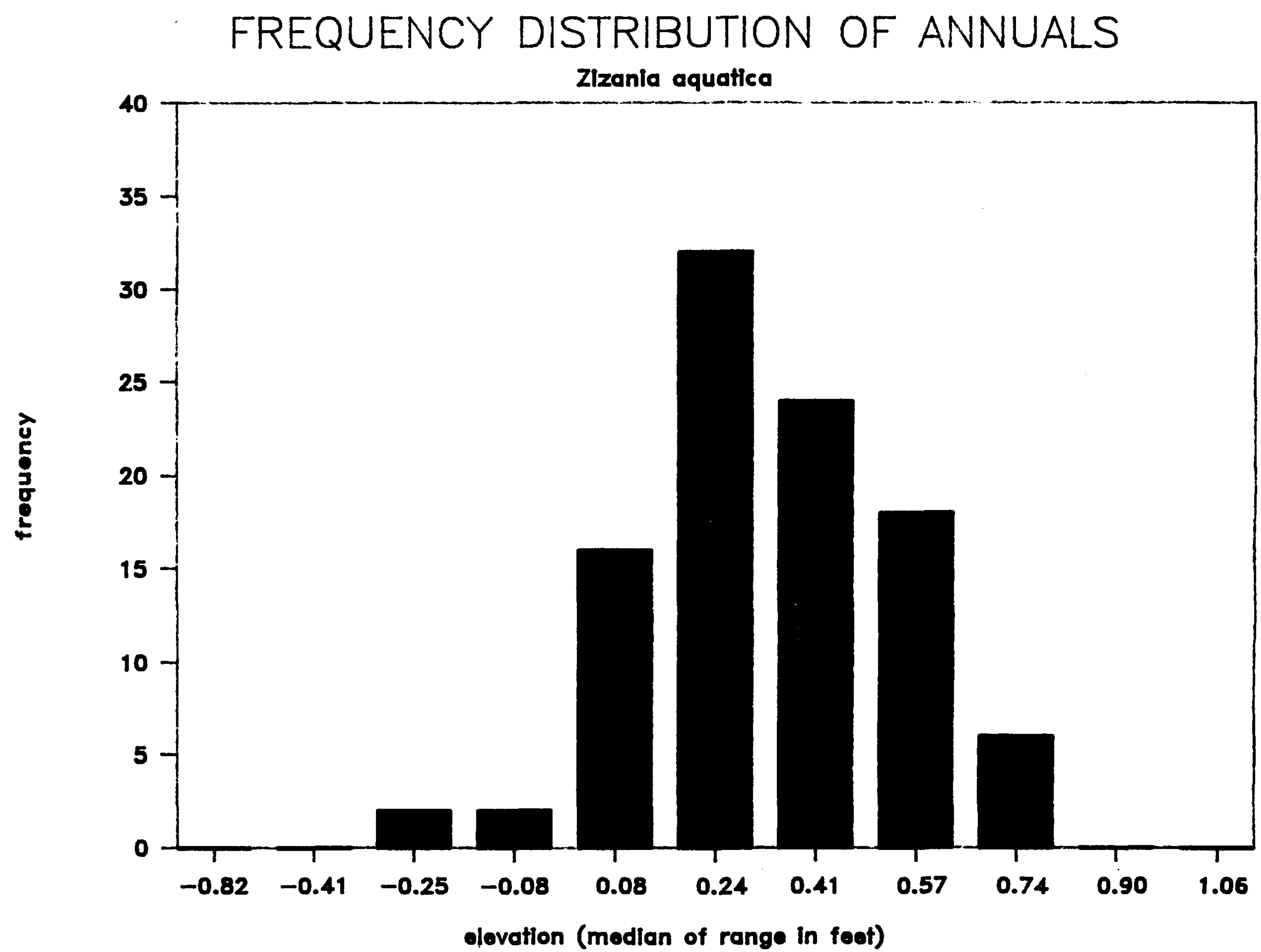
APPENDIX II. ELEVATION RANGE GRAPHS FOR SWEET HALL MARSH

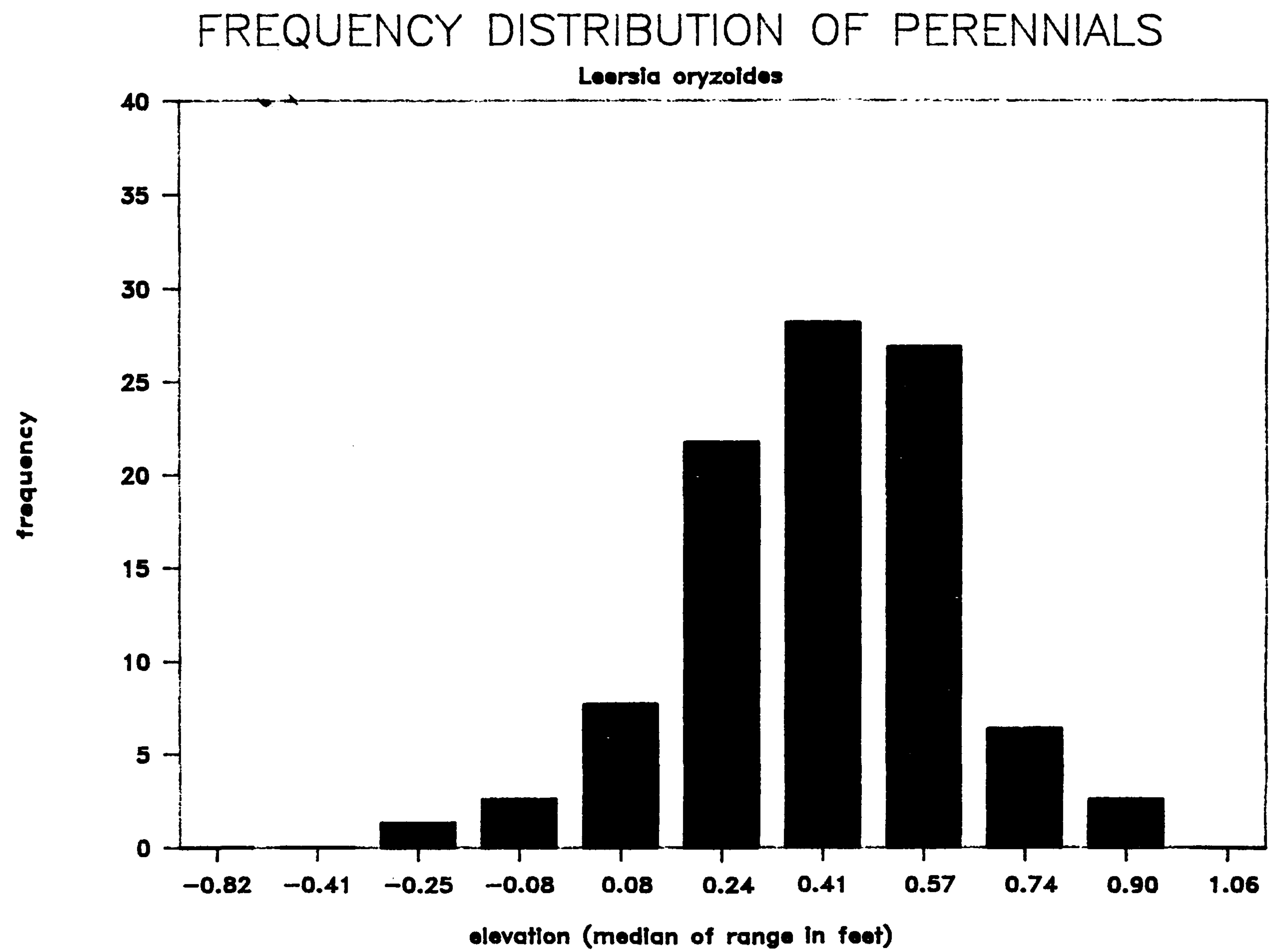


FREQUENCY DISTRIBUTION OF ANNUALS
Amaranthus cannabinus
40
35
30
25
20
15
10
5
0
frequency
−0.82
−0.41
−0.25
−0.08
0.08
0.24
0.41
0.57
0.74
0.90
1.06
elevation (median of range in feet)

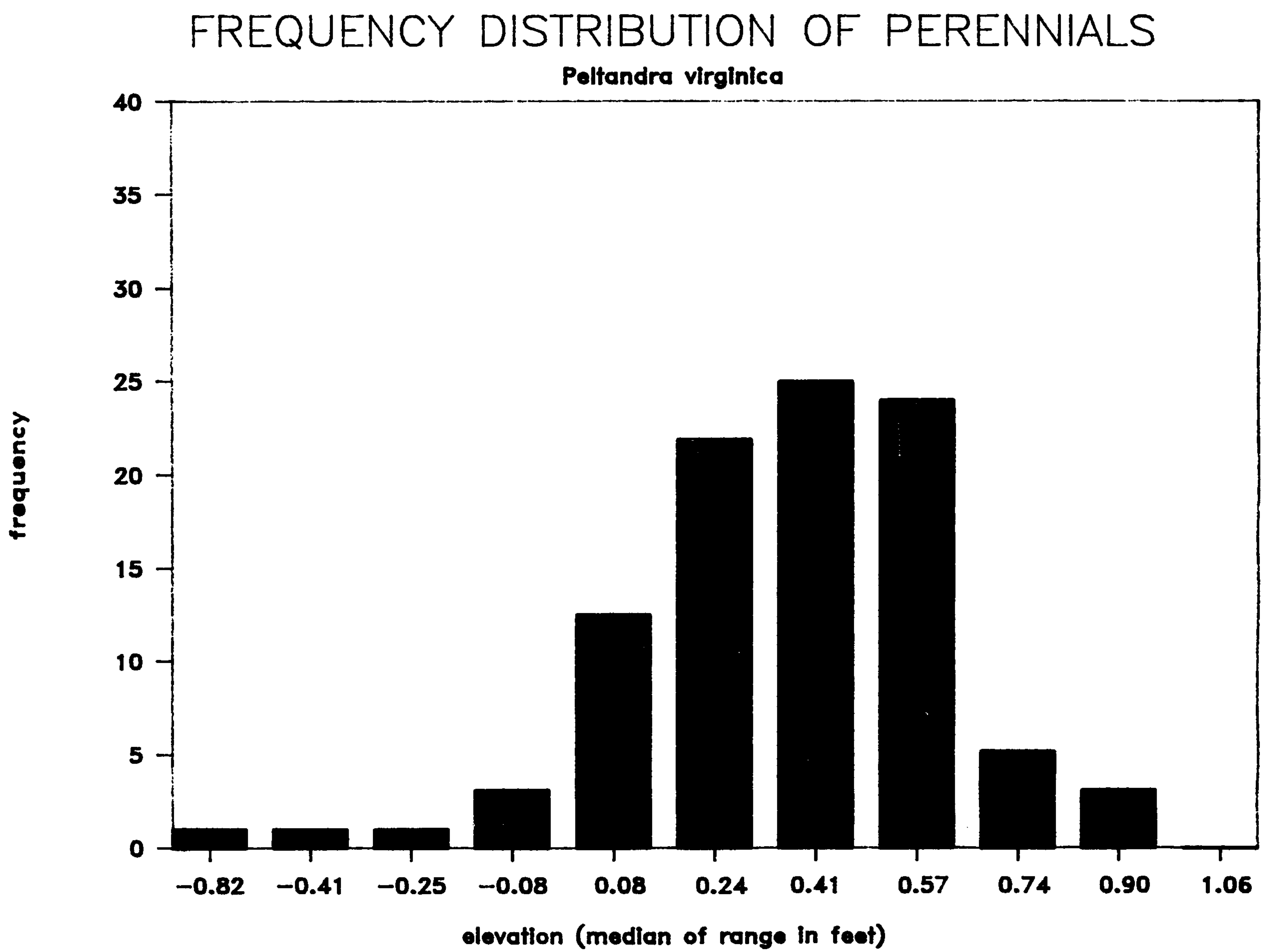

FREQUENCY DISTRIBUTION OF ANNUALS
Bidens cernua
frequency
40
35
30
25
20
15
10
5
0
-0.82
-0.41
-0.25
-0.08
0.08
0.24
0.41
0.57
0.74
0.90
1.06
elevation (median of range in feet)


FREQUENCY DISTRIBUTION OF ANNUALS
Echinochloa walteri
frequency
40
35
30
25
20
15
10
5
0
−0.82
−0.41
−0.25
−0.08
0.08
0.24
0.41
0.57
0.74
0.90
1.06
elevation (median of range in feet)

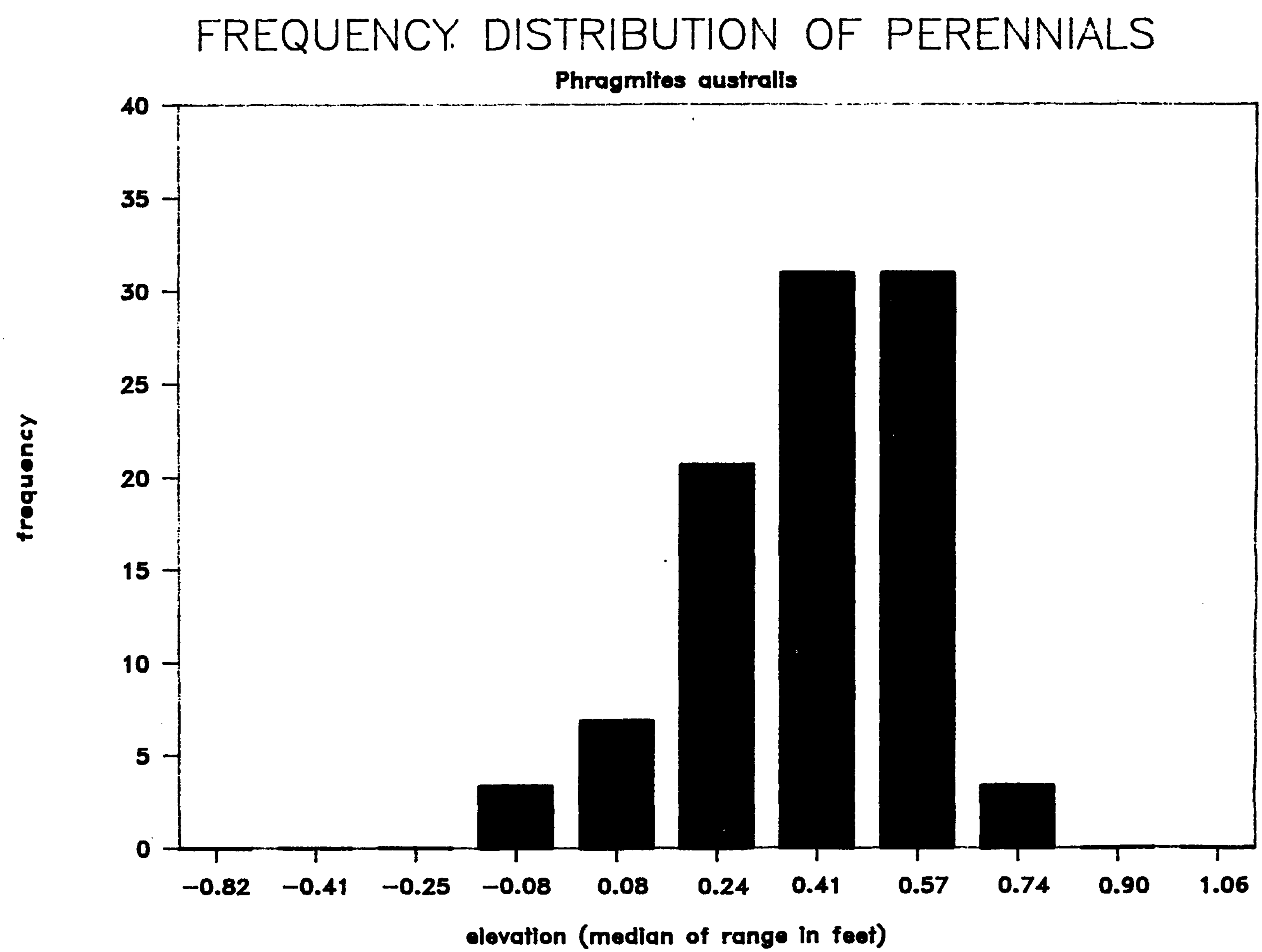

FREQUENCY DISTRIBUTION OF ANNUALS
Zizania aquatica
frequency
40
35
30
25
20
15
10
5
0
-0.82
-0.41
-0.25
-0.08
0.08
0.24
0.41
0.57
0.74
0.90
1.06
elevation (median of range in feet)

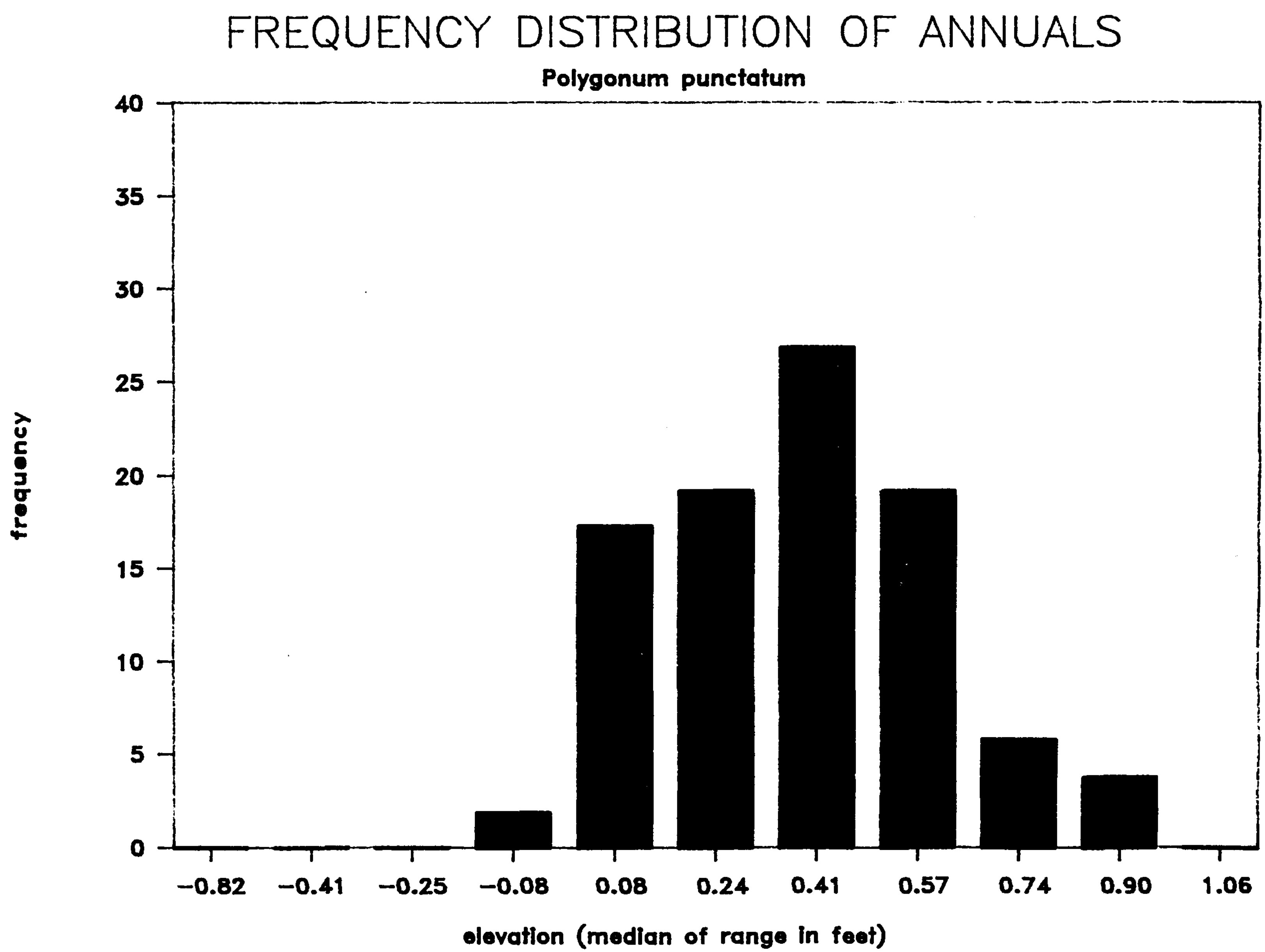


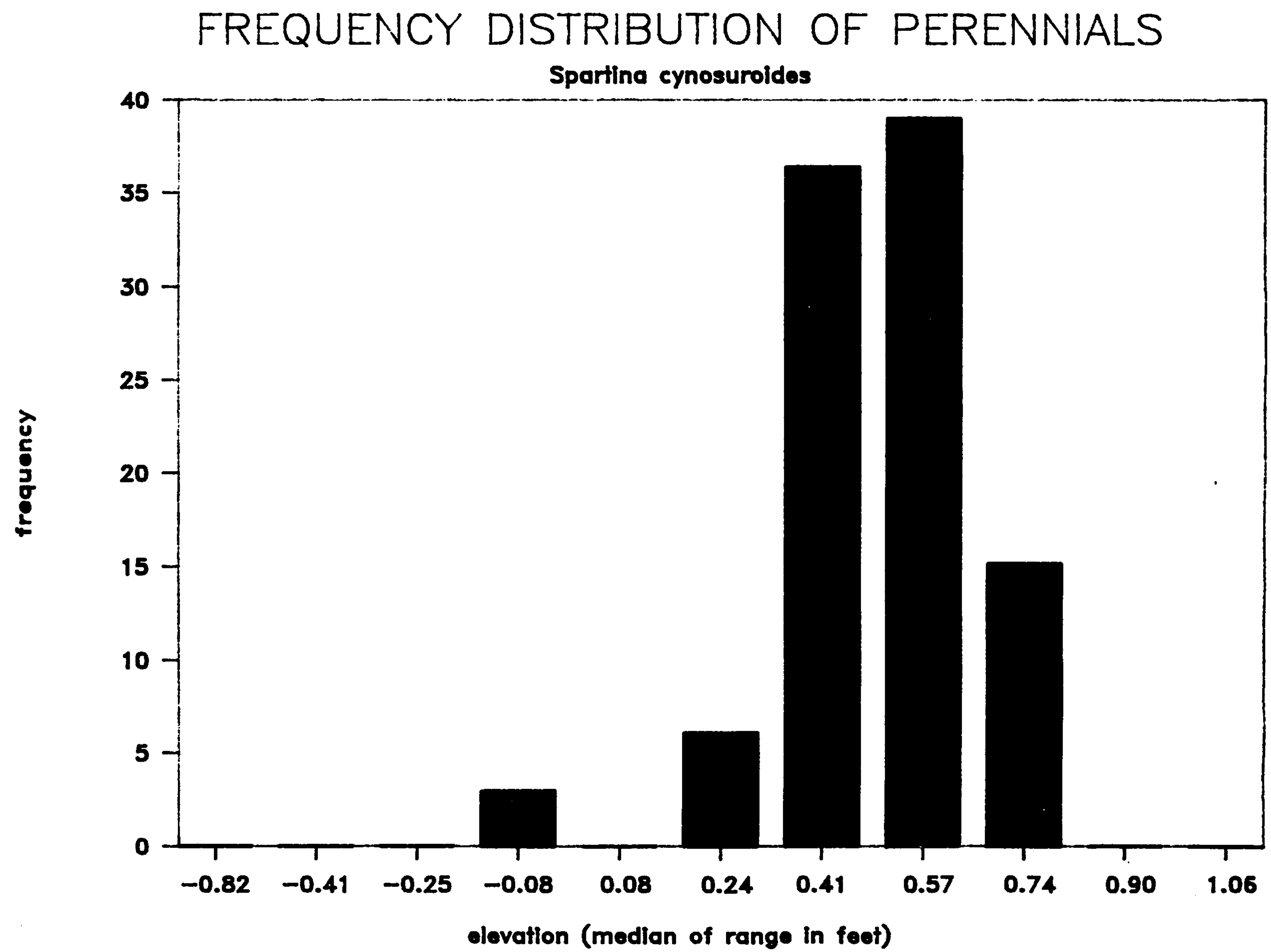
FREQUENCY DISTRIBUTION OF PERENNIALS
Leersia oryzoides
frequency
0
5
10
15
20
25
30
35
40
−0.82
−0.41
−0.25
−0.08
0.08
0.24
0.41
0.57
0.74
0.90
1.06
elevation (median of range in feet)



FREQUENCY DISTRIBUTION OF PERENNIALS
Peltandra virginica
frequency
40
35
30
25
20
15
10
5
0
−0.82
−0.41
−0.25
−0.08
0.08
0.24
0.41
0.57
0.74
0.90
1.06
elevation (median of range in feet)


FREQUENCY DISTRIBUTION OF PERENNIALS
Phragmites australis
frequency
40
35
30
25
20
15
10
5
0
-0.82
-0.41
-0.25
-0.08
0.08
0.24
0.41
0.57
0.74
0.90
1.06
elevation (median of range in feet)


FREQUENCY DISTRIBUTION OF ANNUALS
Polygonum punctatum
frequency
40
35
30
25
20
15
10
5
0
−0.82
−0.41
−0.25
−0.08
0.08
0.24
0.41
0.57
0.74
0.90
1.06
elevation (median of range in feet)



FREQUENCY DISTRIBUTION OF PERENNIALS
Spartina cynosuroides
frequency
40
35
30
25
20
15
10
5
0
-0.82
-0.41
-0.25
-0.08
0.08
0.24
0.41
0.57
0.74
0.90
1.06
elevation (median of range in feet)

APPENDIX III. TIDAL DATUM TRANSFER FOR SWEET HALL MARSH

TIDAL DATUM TRANSFER FOR SWEET HALL MARSH

1. Transfer of mean sea level (MSL) Tidal Datum from Gloucester Point to Sweet Hall Marsh.

   a. Calculation of the change in MSL:

      ^MSL = MMSL-MMSL $_b$ where: ^MSL=change in MSL

      a=Sweet Hall Marsh

      b=Gloucester Point

      MMSL=monthly mean sea level

      $MMSL_a$ was calculated from the December, 1986 measured tide record from Sweet Hall Marsh (see SH_DEC86_DATA) and $MMSL_b$ was calculated from the December, 1986 measured tide record from Gloucester Point (see GLPT_DEC86_DATA).

      $MMSL_a$ = 2.883 ft. and

      $MMSL_b$ = 2.851 ft.

      Therefore: ^MSL = 2.883-2.851

      ^MSL = 0.032 ft.

   b. Calculation of MSL_a:

      MSL_a = MSL_b + ^MSL.

      MSL_b has been determined from the 19-year Gloucester Point tide record: MSL_b = 2.640 ft.

      Therefore: MSL_a = 2.640 + 0.032;

      MSL_a = 2.672 ft.

2. Transfer of mean tide level (MTL) Tidal Datum from Gloucester Point to Sweet Hall Marsh.

   a. $MTL_a = MTL_b + \hat{}MTL$ where $\hat{}MTL$=change in MTL;

      a=Sweet Hall Marsh and

      b=Gloucester Point;

   and $\hat{}MTL = 1/2((MMHW_a + MMLW_a) - (MMHW_b + MMLW_b))$

      where: MMHW=monthly mean high water level and

      MMLW=monthly mean low water level.

   $MMHW_a$ and $MMLW_a$ where calculated from 59 and $MMHW_b$ and $MMLW_b$ from 60 high and low tides of the respective sites in December, 1986 (see MN_HL_DATA and GLPT_DEC86_HL):

   $MMHW_a = 3.917$ ft.,

   $MMLW_a = 1.731$ ft.,

   $MMHW_b = 3.996$ ft. and

   $MMLW_b = 1.743$ ft..

   Therefore: $\hat{}MTL = 1/2((3.917 + 1.731)-(3.996-1.743))$;

   $\hat{}MTL = 2.824-2.706$;

   $\hat{}MTL = 0.118$.

   MTL_b has been determined from the 19-year Gloucester Point tide record: $MTL_b = 2.660$.

   Therefore: $MTL_a = 2.660 + 0.118$;

MTL_a = 2.778

3. Determination of the mean high an mean low water of Sweet Hall Marsh (MHW_a and MLW_a).

a. Determination of the range ratio:

$RR = (MMHW_a - MMLW_a)/(MMHW - MMLW_b)$;

RR = (3.917-1.731)/(3.996-1.743);

RR = (2.186)/(2.253);

RR = 0.970.

b. Determination of MHW_a and MLW_a:

$MHW_a = MTL_a + (MN_b * RR / 0.5)$ and

$MLW_a = MTL_a + (MN_b * RR / 0.5)$ where: MN_b = mean tide range at Gloucester Point.

MN_b has been determined from the 19-year Gloucester Point tide record: MN_b = 2.450 ft..

Therefore: MHW_a = 2.778+(2.45*0.970/0.5);

MHW_a = 2.778+(1.188);

MHW_a = 3.966 ft. and

: MLW_a = 2.778-(1.188);

MLW_a = 1.590 ft..

b. Calculation of Sweet Hall Marsh tide range (R_a):

$R_a = MN_b * RR$;

R_a = 2.450*0.970

$R_a = 2.377$ ft..

4. Transfer of Gloucester Point tide to Sweet Hall Marsh (equivalent observed tidal height).

$HW_a = ((HW - MSL_b) * RR) + MSL_a$ where: HW = tide height.

For Sweet Hall Marsh the transfer algorithm is:

$HW_a = ((HW - 2.640) * 0.970) + 2.670$

VITA

James Ernest Perry, III

The author was born in South Kingstown, Rhode Island, April 17, 1949. He graduated from North Kingstown High School in 1968 and received a B.S. degree in Biology from Murray State University, Murray, Kentucky, in August, 1978.

After several years as a private consultant, the author enrolled in the Virginia Institute of Marine Science (VIMS), School of Marine Science, College of William and Mary, in the fall of 1986. He is currently employed as a Marine Scientist at VIMS.